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FOREIGN OBJECT DAMAGE TO TIRES OPERATING IN A WARTIME ENVIRONMENT

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Over the past 5 years, various efforts addressed the problems associated with Foreign Object Damage (FOD) to aircraft operating in a debris strewn environment following an airbase attack. These efforts include engine object ingestion probability, engine (FOD) damage, aircraft damage from tire lofted foreign objects, external stores FOD, tire cutting FOD, and the operability of tires subjected to FOD. This report was written to provide a summary and preliminary assessment to the tire cutting FOD portion of the overall post-attack FOD program. The report summarizes the approach and results of tests on over 126 aircraft tires which were tested in a simulated post-attack environment under full scale test conditions. Tests tires included F-16 main and nose, and an F-4 nose tire setup. Test variables included speed, load, size, pressure, tire type, turning, water effects, debris type, debris size, debris distribution, braking, and combined variable effects. Analysis consideration involved cut types, cut depths, number of cuts, cut/hit probabilities, tire failures, and aircraft operational impacts.

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FOREWORD

This effort was performed in-house by the Aircraft Launch and Recovery Branch, Vehicle Subsystems Division of the Wright Research and Development Center (now Wright Laboratory). The effort was conducted as part of a jointly funded program, between WRDC and AFESC Tyndall AFB FL, to determine the impact of FOD (Foreign Object Damage) to aircraft operating in a post-attack environment. This part of the program addressed the issues of tire cutting damage sustained as a result of operating an aircraft over post-attack debris and what measures would be needed to overcome any problems disclosed. The effort was conducted under Work Unit Numbers 24020146 and 24020157 entitled "Ground Contacting Systems" and "Vehicle Subsystems Integrity Program" respectfully. The test effort was conducted from 1 June 1986 to 1 November 1988 with data reduction and analysis continuing into October 1989. All of the cutting tests reported in this report were conducted at the Naval Air Engineering Center (NAEC), Lakehurst New Jersey, and the author acknowledges the engineering support provided by Mr. Jack Schaible of the NAEC. The author also acknowledges the technical support provided by Ms Gwen Patterson of WL/FIVMB.

This report was submitted by the author in November 1990.

This report has been reviewed and is approved.

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LIST OF ACRONYMS & ABBREVIATIONS

ACRONYM	DESCRIPTION
A	Amperes
ADJ	Adjusted
AFESC	Air Force Engineering Services Center
AFFTC	Air Force Flight Test Center
CAM	Camber
CBR	California Bearing Ratio
D	Drag
ENG	Engineer
FOD	Foreign Object Damage/Debris
GY	Goodyear
LTH	Length
MIC	Michelin
MLG	Main Landing Gear
MPH	Miles Per Hour
NASC	Naval Air Systems Command
NLG	Nose Landing Gear
PRO	Propulsion
PSI	Pounds Per Square Inch
RETRD	Retreaded Tire
S	Side
SHRAP	Shrapnel
TCTV	Tire Cutting Test Vehicle
UDRI	University of Dayton Research Institute
V	Vertical
VEH	Vehicle
WL	Wright Laboratory
WRDC	Wright Research & Development Center
WTH	Width

SECTION I

INTRODUCTION

The purpose of this effort is to provide a preliminary assessment as to the sensitivity for tire cutting under varied operating conditions. This assessment is limited and non statistical in nature. The objective of the study is to provide preliminary guidance which can be used for both near-term research programs, detailed statistical analysis efforts, and initial operations analysis applications.

The study itself is confined to considering cut depths and numbers of cuts. No analysis considerations are given to cut types, locations, detailed loads, specific cut limits, or other damage. The study cut data are grouped into five cuts areas consisting of Total Cuts, 0-5 (32nds), 6-10 (32nds), 11-15 (32nds), and 16+ (32nds) depth. A total of 22 analysis extractions are derived from the original data base generated from the tire cutting test effort (reference 1). These 22 extractions resulted in the generation of 22 different tables whereby single variables can be looked at while all the remaining parameters remain fixed. A complete summary of the 22 analysis extractions and resulting data files are as follows:

SUBJECT AREA		FILE NAME
SPEED EFFECTS ANALYSIS	FILE	SPEED
YAW EFFECTS ANALYSIS	FILE	YAW
RADIAL TIRE ANALYSIS	FILE	RADIAL
PRESSURE EFFECTS ANALYSIS	FILE	PRESSURE
RETREAD TIRE ANALYSIS	FILE	RETRDALL
RETREAD TIRE CONST PATT ANALYSIS	FILE	RETRD
TIRE SIZE ANALYSIS	FILE	SIZE
F-4 LOADS EFFECTS	FILE	F-4LOADS
F-16 LOADS EFFECTS	FILE	F-16LOADS
F-16 WATER EFFECTS LO SPD	FILE	WATER-LO
F-16 WATER EFFECTS HI SPD	FILE	WATER-HI
F-16 WATER/YAW EFFECTS HI SPD	FILE	WATER-YAW
DEBRIS SIZE EFFECTS GY/RET	FILE	DEB-SIZA
DEBRIS SIZE EFFECTS RETREAD	FILE	DEB-SIZR
SHRAPNEL (DEBRIS TYPE) EFFECTS	FILE	SHRAP
SHRAP (ABOVE) DEEP CUTS ADJUSTED	FILE	SHRAP 1
BRAKING ANALYSIS ALL BEDS	FILE	BRAKED
BRAKING ANALYSIS 6/4 BEDS	FILE	BRAKING 1
COMBINED YAW/BRAK + PRESS	FILE	COMBO-BR
COMBINED YAW/BRAK ALL PRESS	FILE	COMBO
COMBINED (TABLE 21 SEP COMPARE)	FILE	COMBOA
DEBRIS DISTRIBUTION EFFECTS	FILE	DISTRIB

The resulting output consists of various Lotus worksheet files which were then printed out in table form and analyzed both visually and graphically in Section III of this report. A summary of the file contents, resulting table number and

number of tests included in the analysis is as follows:

SPEED EFFECTS ANALYSIS	15 TESTS	TABLE # 2
YAW EFFECTS ANALYSIS	13 TESTS	TABLE # 3
RADIAL TIRE ANALYSIS	13 TESTS	TABLE # 4
PRESSURE EFFECTS ANALYSIS	9 TESTS	TABLE # 5
RETREAD TIRE ANALYSIS	17 TESTS	TABLE # 6
RETREAD TIRE CONST PATT ANALYSIS	10 TESTS	TABLE # 7
TIRE SIZE ANALYSIS	17 TESTS	TABLE # 8
F-4 LOADS EFFECTS	9 TESTS	TABLE # 9
F-16 LOADS EFFECTS	14 TESTS	TABLE # 10
F-16 WATER EFFECTS LO SPD	10 TESTS	TABLE # 11
F-16 WATER EFFECTS HI SPD	11 TESTS	TABLE # 12
F-16 WATER/YAW EFFECTS HI SPD............	4 TESTS	TABLE # 13
DEBRIS SIZE EFFECTS GY/RET	29 TESTS	TABLE # 14
DEBRIS SIZE EFFECTS RETREAD	17 TESTS	TABLE # 15
SHRAPNEL (DEBRIS TYPE) EFFECTS	16 TESTS	TABLE # 16
SHRAP (ABOVE) DEEP CUTS ADJUSTED	16 TESTS	TABLE # 17
BRAKING ANALYSIS ALL BEDS	17 TESTS	TABLE # 18
BRAKING ANALYSIS 6/4 BEDS	13 TESTS	TABLE # 19
COMBINED YAW/BRAK + PRESS	14 TESTS	TABLE # 20
COMBINED YAW/BRAK ALL PRESS	29 TESTS	TABLE # 21
COMBINED (TABLE 20 SEP COMPARE)	29 TESTS	TABLE # 22
DEBRIS DISTRIBUTION EFFECTS	12 TESTS	TABLE # 23

Future Studies and Analysis

The original test plan to generate these data was formulated to accommodate detailed operational studies in this area. With all of the above data in statistical form, these operational studies would first generate operational spectrums for specific aircraft/tire combinations and then combine these with expected levels of airfield debris. The resulting spectrum would then be segmented into detailed sub elements conforming to the available statistical form data. Typical sub elements will include taxi, takeoff, landing, and taxi segments each of which would be further segmented into multiple turning and braking segments each at different loading conditions. This model when combined with airfield debris models will permit very detailed and accurate studies of expected tire cutting as a function of aircraft operation and runway cleanliness to be made.

SECTION II

PROGRAM EVOLUTION

Broadbase Program

The tire cutting program discussed in this report is actually an outgrowth of a larger FOD program started in 1984. This original FOD effort consisted of assessing the FOD relationships to aircraft operations in a post attack or debris laden environment. The overall objective of this larger program was to generate test data to fill critical voids so that airfield cleanliness costs could be traded against some acceptable level operational FOD damage to the aircraft.

Original program emphasis was in three principal areas. The first consisted of aircraft engine damage occurring from the lofting of debris from the tires into the engine or direct vortex suction of debris off the ground into the engine. The second area of emphasis involved the lofting of debris by the tires against the aircraft itself resulting in damage to aircraft structures mechanical subsystems or external stores. The final area of concern was that of tire cutting whereby the effects of running high pressure tires over post-attack debris such as rocks and shrapnel would have to be analyzed.

Initial program emphasis was on the first two of these areas in that it was originally theorized that the tire cutting area was the least critical of the three. As a result, an extensive test and evaluation effort was started to study the effects of tire lofting and resulting lofted debris damage. Early in the lofting test effort, however, it was noted that the tires used for lofting tests were being very severely cut up during these tests. As a result, a separate and independent test effort to study tire cutting effects was established. The final results of the tire cutting would ultimately serve to show that the tire cutting area was indeed the most critical of the three areas studied in a post attack environment.

Test results from all three areas were quite interesting with some rather unexpected results occurring from applying wartime criteria rather than peacetime constraints. This report only covers the tire cutting portion and only provides a summary type analysis of that area. Additional details of the tire cutting portion of the effort are contained in references 1 through 5 and reference 12. Additional details of the tire lofting, engine degradation, mechanical subsystem and airframe damage, portions of the effort are contained in references 6 through 9. A report on the operational effects of all of these areas along with the generation of wartime cleanliness criteria is being prepared and will be available in the near future.

Program Participants

All of these previously discussed efforts were jointly undertaken and sponsored by WRDC/FIVMB Wright Patterson AFB, and AFESC/RDCR Tyndall AFB Florida. Support contractors involved in these efforts included the University of Dayton Research Institute, Dayton, Ohio; Physics Applications Inc. Dayton, Ohio; the BDM Corporation located in McLean, Virginia; Sverdrup Technology Inc, Tullahoma, Tennessee; and Commercial Metals Fabricators of Dayton, Ohio. Testing organizations involved in these programs included the Naval Air Systems Command, Lakehurst, NJ; The Air Force Flight Test Center, Edwards AFB, California; the UDRI Impact Dynamics Laboratory, Dayton, Ohio; the Mobility Development Laboratory, Wright Patterson AFB, Ohio and the Landing Gear Development Facility, Wright Patterson AFB, Ohio.

SECTION III

TEST PROGRAM SUMMARY

Purpose

All data and resulting data tables generated in this analysis were the result of an extensive tire cutting test effort conducted over a 2-year period. The subject test program was conducted at the Naval Air Engineering Center (NAEC) jet track facility located at Lakehurst, NJ. and involved over 150 tests specifically targeted for tire cutting studies. Details relating to test vehicle design, vehicle capabilities, facility operation, test methods, instrumentation, and data reduction techniques are quite extensive and are included in references 1, 2, 3, 5, and 12. This section summarizes work done to support the analysis conducted in this report and to outline what data and facilities are available for future efforts. To provide this background, brief summaries of important areas are presented in the following sections. Additionally, Section IV has been included which covers the test vehicle and test setup in further detail.

Test Vehicle

The TCTV (Tire Cutting Test Vehicle) consists of a 20-30 ton vehicle designed to be accelerated to speeds in excess of 200 MPH along a 6000-8000 ft test track. The test tire and/or landing gear is mounted to the vehicle by a hinged cantilevered boom extending forward of the vehicle. Loading of the tire or gear is accomplished with of dead weights mounted directly to the top of the cantilever structure. More detailed descriptions of this arrangement are included in reference 1. Typically tire loads of up to 17,000 lbs can be accommodated involving side and drag loads of 8,000 & 23,000 lbs respectively. The vehicle was qualified to speeds of over 150 MPH. A complete listing of the vehicle's capabilities are also noted in Section IV.

Test Plan

Prior to the implementation of this effort, a fully coordinated test plan was developed. The resulting plan considered user requirements, operational factors, cost trades, available resources, and a parametric analysis of what variables needed to be included along with their associated priority. The results of this planning phase are included in reference 3.

Instrumentation

Instrumentation contained on the test vehicle includes the capability to measure vertical, side, & drag loads throughout the test run. These loads are measured at the axle and through calibration, and conversion techniques can be directly correlated to loads occurring in the tire footprint area. Additional instrumentation includes the measurement of surface speed and brake pressure. Visual data can also be obtained with two on-board cameras capable of both high and low speed visual acquisition.

Data Acquisition

In addition to the dynamic data noted above, field calibration techniques, tire inspection techniques, and test parameter logging techniques had to be developed. Inspection methods required the measurement of severely cut tires in a high pressure inflated mode. Calibrations had to be completed rapidly in the field, and preliminary test results had to be rapidly assessed to permit test schedule changes to optimize the total data acquisition effort. A summary of these methods and activities are included in References 1, 2, 5, and 12.

Additional Tire Testing

One final area of work that was conducted in this program was the dynamic testing of cut tires. This phase of the effort consisted of subjecting severely cut tires to an operational taxi/takeoff load speed profile on an aircraft tire test dynamometer. The goal here was to determine if a damaged tire could still be used in an emergency for at least one or two taxi/takeoff landing/taxi cycles. This effort is not discussed in this report but additional information can be found in references 5 and 12.

SECTION IV

TEST VEHICLE/TEST SETUP

Test vehicle

Fabrication of the TCTV was completed on 3 January 1986. Figure 1 shows the vehicle installed at the NAEC Jet Track Facility and shows the deadload, boom structure, and associated systems. The particular test setup shown consists of an F-16 main wheel and tire installed for a 120-mph run. The TCTV is composed of four primary systems and various subsystems, as shown in Table 1. The first of these involves three options for providing forward speed to the test vehicle itself. The first option consists of using an MRS tractor system for speeds of 0-18 mph. The MRS (model 200) represents a high torque/high rimpull capability for use in high drawbar pull situations such as high yaw angle or soft soils testing. For lower drawbar situations a second option of lower torque capacity can be used for speeds of up to 30 mph. This option consists of utilizing a standard 5-ton truck, and a modified pusher plate system. For speeds in excess of 30 mph, the third system available is the standard NAEC jet car push mode. The pusher system consists of a rear push acceleration to some velocity above the desired test speed, and releasing the TCTV prior to engagement of the test section. This procedure eliminates any pusher bias through the test section and allows the vehicle to stabilize yielding more constant behavior through the testbed and over the entire range of all tests conducted.

Table 1 TCTV System/Subsystem Breakdown

A. Speed Generation System
   1. MRS Tractor (Low Geared)
   2. Hi Geared Travels Pushers
   3. Jet Car Pusher

B. Dead Load with Railed Guidance

C. Test/Support Systems
   1. Support Structures
   2. Instrumented Axles
   3. Instrumentation System
   4. Power Supply
   5. Load/Lift/Stop System
   6. Braking System

D. Arresting System
   1. Cable Catcher
   2. Arrestor Brakes

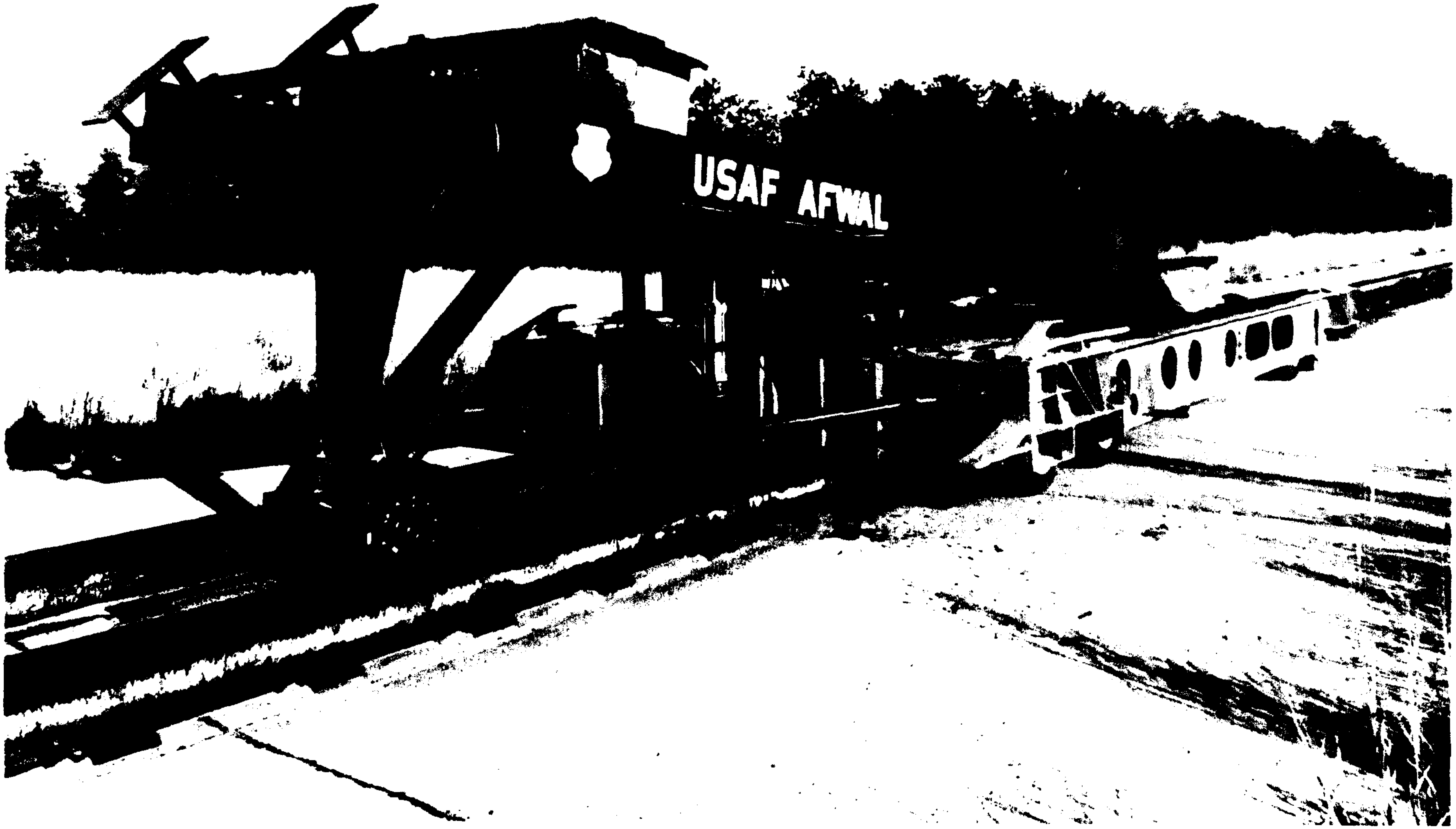


Figure 1 Finally Fabricated Tire Cutting Test Vehicle

The second system noted in Table 1 consists of the deadload, with railed guidance. The deadload is comprised of all the yellow structure shown in Figure 1. This structure is a 40,000-lb steel frame, supported by eight wheels, and is guided on two 10WF49 steel rails.

The third system noted in Table 1 comprises the heart of the entire test vehicle. The majority of subsystems in this area are represented in black in Figure 1. Specific capabilities and operation of all of these systems is contained in reference 1.

The final system noted in Table 1 consists of the arresting system to safely catch and arrest the entire test vehicle following a high speed test. This system is comprised of a cable catcher located on the deadload, and two ground based arrester systems. The ground based arrester system consists of a suspended cable (which engages the cable catchers) attached to an arrester tape leading to a standard M-21 Naval arresting system.

In addition to the four systems previously discussed, several additional capabilities are worth mentioning. Figure 1 only depicts one particular test setup but different aircraft axles can be substituted to include other tires or aircraft types. In addition, the entire axle support structure can be easily removed, and an actual landing gear substituted in its place. This latter change was actually accomplished in this program with an F-4 nose landing gear system. It should be finally noted that the axle/instrumentation calibration system for the vehicle is of field design, and all calibrations can be accomplished on site.

Test Vehicle Specification Summary:

The resulting TCTV represents a significant advancement for the test and evaluation of aircraft landing gear systems. The range of capabilities extends from low speed (up to 10 mph) soft surface (CBR 3-4) testing, all the way to high speed (200 mph +) testing on actual runway surfaces. The vehicle can be utilized for full scale landing gear component studies involving aircraft up to 40,000 lbs, or a single gear weight of 17,000 lbs. The vehicle capitalizes on a forward mounted design approach to eliminate the effects of carriage airflow interference on the actual test sections. This fact results in a highly controllable test environment and the additional capability to include advanced test articles such as air cushion cells or dynamically scaled models. A summary of the current capabilities of the TCTV, as they relate to aircraft landing gear test and evaluation requirements, is as follows:

Load Limits @ Ground Contact Point
- o Side = 8,000 lbs
- o Drag = 23,000 lbs
- o Vertical = 17,000 lbs (maximum)
  4,500 lbs (minimum)

Speed Capabilities (Hard Surface)

- o 0-15 mph without jet car
- o 0-30 mph potential, without jet car
- o 30-200 mph with jet car

Soft Surface Capabilities

- o CBR to 3 or 4
- o 0-10 mph speed

Tire/Wheel/Brake Mountings (Available)

- o F-16/F-4 Nose Axle
- o F-16 Main Axle
- o Adaptable to other specially made axles

Instrumented Capabilities

- o Surface Side Load
- o Surface Drag Load
- o Vertical Load
- o Surface Speed
- o Brake Pressure

Axle Block Positioning Control (Degrees)

- o Camber = 0, ±1, ±2
- o Yaw = 0 to ± (measured)
  0 to ± 5 1/2 (max limit)

Test Surfaces

- o Concrete
- o Asphalt
- o Soils
- o Wet Surfaces
- o Standing Water
- o Debris Laden Hard Surfaces
- o Specialized Sections

Visual Data

- o On-board Camera (high speed)
- o On-board Camera (standard speed)

Environmental Limits

- o 10 to 100 F Ambient (operating range)
- o Operable in Rain/Snow/or Ice

Test Costs/Times/Test Rates

- o Low Speed Shot = Approximately $ 500
- o High Speed Shot = Approximately $3,000

Test Costs/Times/Test Rates (continued)

- o Wheel Change Time = 10 minutes
- o Low Speed Test Rate = 5-7 per 8 hrs
- o High Speed Test Rate = 3-4 per 8 hrs

Field Calibration Loads (Available Capacity, **NOT_LIMITS**)

o Locked Wheel	(S =	8,000 lbs)
(with brake)	(V =	17,000 lbs)
	(D =	4,000 lbs)
o Choked Wheel	(S =	8,000 lbs)
	(V =	17,000 lbs)
	(D =	2,000 lbs)

Axle Limits

o F-16 MLG	S =	8,000 lbs
	V =	17,000 lbs
	D =	23,000 lbs
o F-4 NLG	S =	3,000 lbs
	V =	6,000 lbs
	D =	4,000 lbs

Braking System

- o Max Pressure = 1,500-psi capacity
  600-psi operational limit
- o Pressure Control = Direct or Feedback
- o Max Energy = 55 million ft lbs
  (from $E_k = \frac{1970}{2} v^2$), v = ft/s @ 160 mph

Testbed Lengths Available

- o 0-15 mph = 5,000 ft in rail
  400 ft nonrail
- o Max mph = 1,500 ft in rail
  300 ft nonrail

On board Power (2 Generators)

- o 1,800 watts, 120 volt, 60 cycle, 15A
  (Sears Model 580.327111)
- o 2,250 watts, 120 volt, 60 cycle, 15A

Boom Lift Specifications

- o Cylinder Limit = 3000-psi Heavy Duty Service
  5000-psi Shock
- o Max lift load = 24, 900 lbs @ 3000 psi
- o Cylinder Spec = 3 1/4 HHC13K

Test Setup

The test setup utilized for this test effort is noted in the Figure 2 generic arrangement. Specific details relative to the vehicle, track layout, and testing techniques will not be presented in that they are fully covered in references 1 and 2. The data presented in this report contain references to push distances,

push vehicles and tested layouts which should be understood for proper data analysis.

For this test effort, two push modes were utilized. The first is a low speed mode (0-25 mph) where a push distance ranging from 1000 to 2500 feet was required to accelerate to the desired testbed speed. For the higher speed mode (30-200 mph), a jet car was utilized which entailed push distances of up to 6500 ft. The test bed itself ranged from 250 to 500 ft in length. Early in the program, numerous patterns and layout techniques were analyzed which included X patterns, Z patterns, random layouts, straight across rows, in line rows, and diagonals. A diagonal pattern was ultimately selected and is shown in Figures 3 and 4. Figure 3 is the F-16 setup and Figure 4 represents the F-4 case. All pertinent data are noted on both the figures with one diagonal representing one tire circumference plus 1 inch to preclude striking the same tire point at each revolution. Horizontal spacing is such that all ribs, grooves, and sidewall points involve a stone contact. Within each figure three beds are noted. The leftmost is the original design. After further consideration one stone was added to both edges to assure that any lateral shift would still involve the same number of stone engagements. This revision is noted in the center drawing. The rightmost drawing represents a halving of the density which was required to both reduce tire damage to manageable levels and to add a more random aspect to the layout. Within the data, these layouts are described as a 9, 6/5, or 5/4 pattern as depicted in these figures.

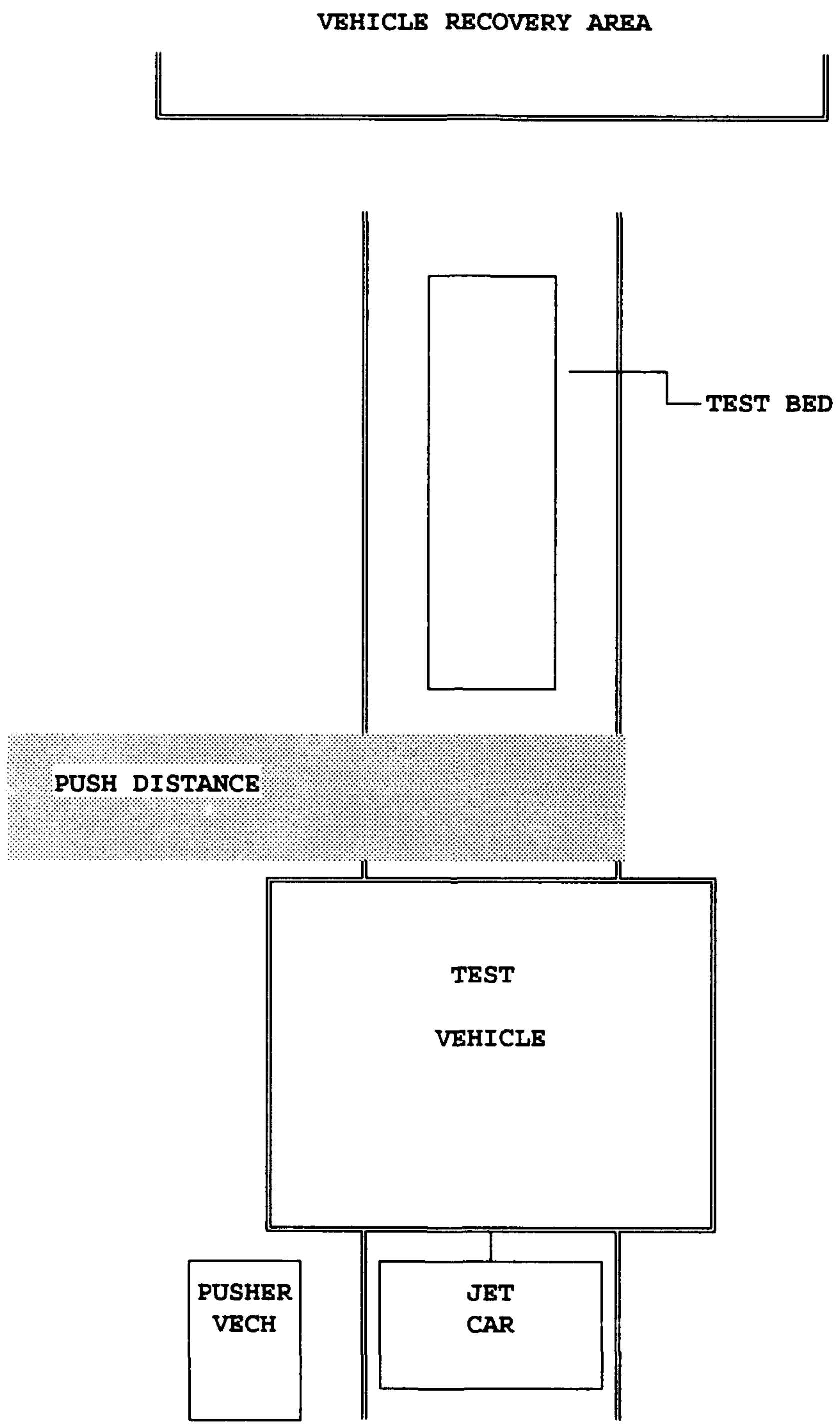
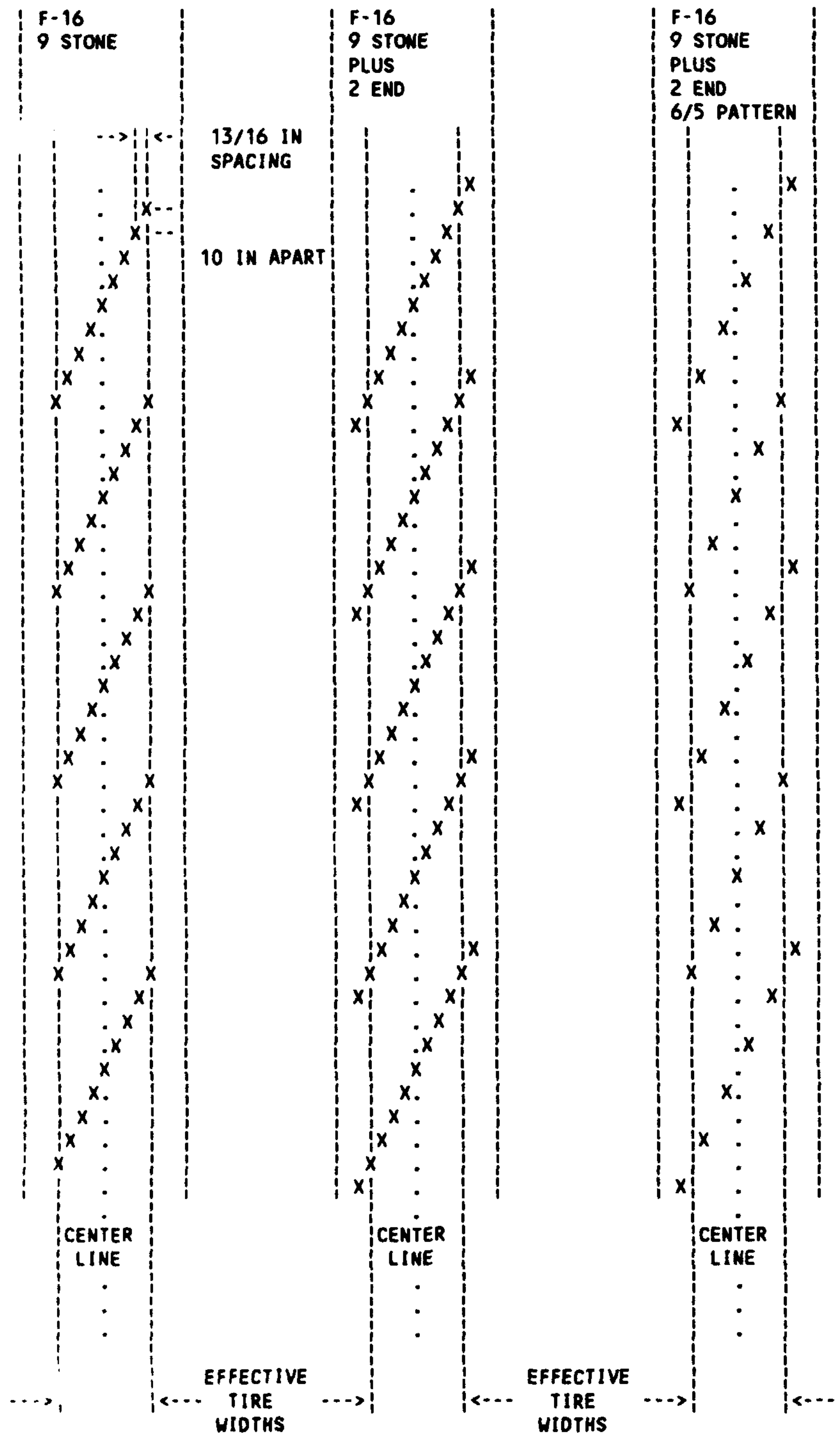


Figure 2 Generic Test Setup



520 FT TEST BED
77 COURSES
693 STONES FULL DENSITY
346 STONES 6/5 DENSITY

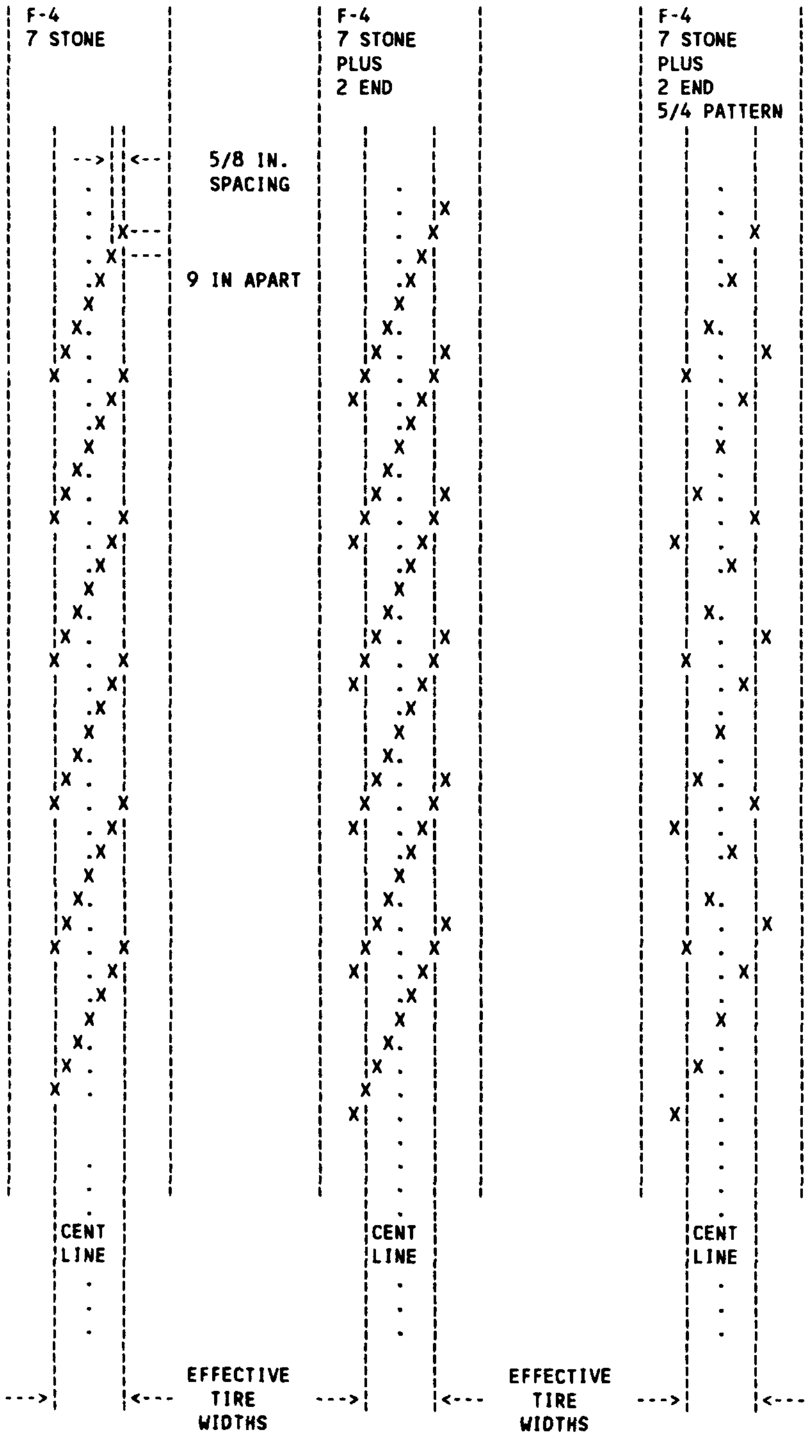
LOADED RADIUS (F-16 MAIN) REG
14300 LBS 275 PSI
11.13 inches
10000 LBS 275 PSI
11.51 inches
7000 LBS 275 PSI
11.73 inches
14300 LBS 225 PSI
10.87 inches

LOADED RADIUS (F-16 MAIN) RADIAL
14300 LBS 275 PSI
10.79 inches

LOADED RADIUS (F-4 OR F-16 NOSE)
4500 LBS 215 PSI
7.805 inches

UNLOADED RADIUS (F-4 OR F-16 NOSE)
4500 LBS 215 PSI
8.852 inches
UNLOADED RADIUS (F-16 MAIN) REG
14300 LBS 275 PSI
12.69 inches
UNLOADED RADIUS (F-16 MAIN) RADIAL
14300 LBS 275 PSI
12.69 inches

Figure 3 F-16 Stone Pattern (Test Setup)



347 FT TEST BED
77 COURSES
539 STONES FULL DENSITY
270 STONES 5/4 DENSITY

LOADED RADIUS (F-16 MAIN) REG
14300 LBS 275 PSI
11.13 inches
10000 LBS 275 PSI
11.51 inches
7000 LBS 275 PSI
11.73 inches
14300 LBS 225 PSI
10.87 inches

LOADED RADIUS (F-16 MAIN) RADIAL
14300 LBS 275 PSI
10.79 inches

LOADED RADIUS (F-4 OR F-16 NOSE)
4500 LBS 215 PSI
7.805 inches

UNLOADED RADIUS (F-4 OR F-16 NOSE)
4500 LBS 215 PSI
8.852 inches
UNLOADED RADIUS (F-16 MAIN) REG
14300 LBS 275 PSI
12.69 inches
UNLOADED RADIUS (F-16 MAIN) RADIAL
14300 LBS 275 PSI
12.69 inches

Figure 4 F-4 Stone Pattern (Test Setup)

SECTION V

PRELIMINARY ANALYSIS

Speed Effects

A total of 15 tests were evaluated to determine the overall effects of speed on cutting damage. Specific tests included are noted in Table 2 where tests are listed in order of decreasing damage. For this case and all subsequent effects noted in the analysis tables, the highest damage severity is defined to be the lowest number of hits required to generate a cut on the tire. In Table 2 and all subsequent tables, this damage parameter is noted in column AU and is listed in order of increasing values unless stated otherwise.

Figure 5 graphically illustrates the Table 2 data and as expected a significant amount of scatter does exist. A potential trend, however, is evident for the case that higher speeds result in higher cutting. In an attempt to clarify this trend a second plot (Figure 6) was generated limiting the cuts considered to be beyond limit or specifically those only over ten 32nds of an inch. For this case, the scatter was less and the higher speed/higher damage theory becomes even more convincing.

For both Figures 5 and 6, only 13 points are used in that two of the Table 2 tests (items 1 & 2) are failed tires. Subsequent post-failure damage could not be determined to allow for any reliable use of these data points.

Yaw Effects

A total of 13 tests are available for an assessment of the effects of yaw or turning on cutting damage. Specific tests included are noted in Table 3 in order of decreasing yaw angle. From this table, one can observe that Column AU (damage level) follows an apparent trend of decreasing damage with decreasing angle. This fact, however, is misleading in that the AU column is for all cuts. When moving to other types of cuts namely deeper values this trend seems to disappear. Figure 7 graphically illustrates this fact where four curves are plotted for the four types of cut sizes. From these curves the potential trends are for increased low depth damage at higher yaw angles but for limited to zero increased damage for larger deep cuts.

Radial Tire Analysis

This analysis consists of comparing four radial tire tests against nine conventional tire tests. The resulting 13 tests are presented in Table 4 in order of increasing damage. In this case, however, increasing damage is confined solely to cuts beyond the limit noted for that particular tire. These two parameters are noted in the two rightmost columns in Table 4 (Beyond Limit Cut Data). It should be noted, however, that the beyond limit nomenclature may not involve true limits in that cut locations (groove, sidewall, or rib) were not considered. Values presented are simply in 32nds of an inch irrelevant of location.

TABLE 2--SPEED TREND ANALYSIS DATA

QUERY CONSTANTS----------> F-16 GY DRY 1.50 0 0 0 14300

NO E1 DATA ALLOWED

TABLE 2--SPEED TREND ANALYSIS DATA

TABLE 1 SPEED ANAL LIST CRITICAL ITEMS PREPARED BY: WRDC/FIVMB/K SCHWARTZ

FILE SPEED DATE 31-Oct 1990

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	BEYOND LIMIT CUT DATA TOTAL	BEYOND LIMIT CUT DATA ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU		
B-4	23 JUL 86	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	98.0	0	0	0	0	0	346	346	FAILURE	0	FAILURE
B-3	23 JUL 86	KS/JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	75.0	1	0	0	0	1	346	346	FAILURE	1	FAILURE
K-3	22 SEP 87	JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	160.9	68	32	23	10	3	346	346	5.09	13	26.62
K-1	22 SEP 87	JS	70	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	101.4	59	37	14	7	1	346	346	5.86	8	43.25
B-1	22 JUL 87	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	38.0	56	37	14	3	2	346	346	6.18	5	69.20
K-2	22 SEP 87	JS	67	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	111.7	48	33	8	6	1	346	346	7.21	7	49.43
K-4	23 SEP 87	JS	72	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	164.8	38	15	14	6	3	346	346	9.11	9	38.44
B-2	22 JUL 86	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	57.0	34	21	10	2	1	346	346	10.18	3	115.33
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	86.50
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	173.00
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	115.33
B-5	23 JUL 86	KS/JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	131.0	27	6	11	10	0	346	346	12.81	10	34.60
D2/I2	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	115.33
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	41.60
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	ERR

SPEED EFFECTS ANALYSIS
ALL CUTS

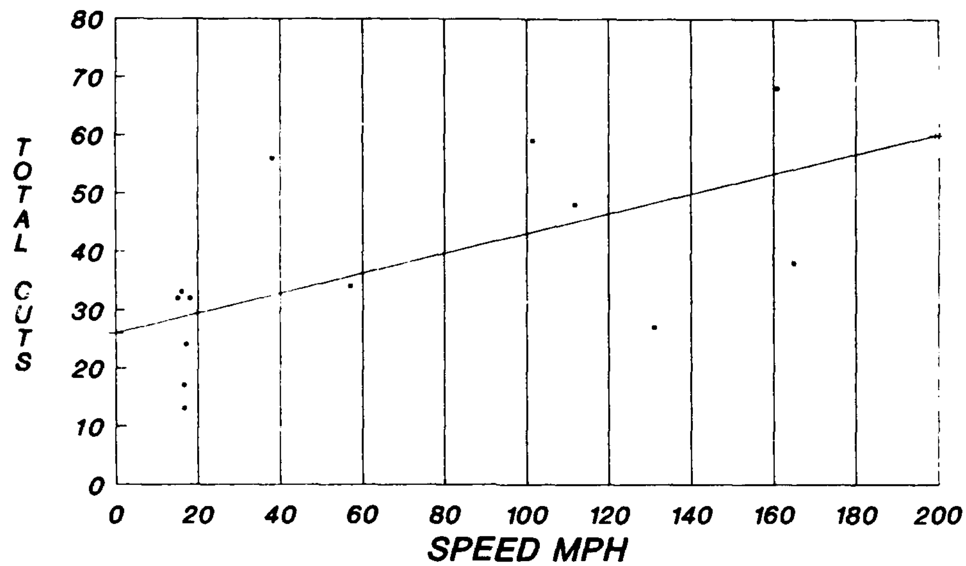


FIGURE 5 SPEED EFFECTS FOR ALL CUTS

SPEED EFFECTS ANALYSIS
OVER 10/32 IN CUTS ONLY

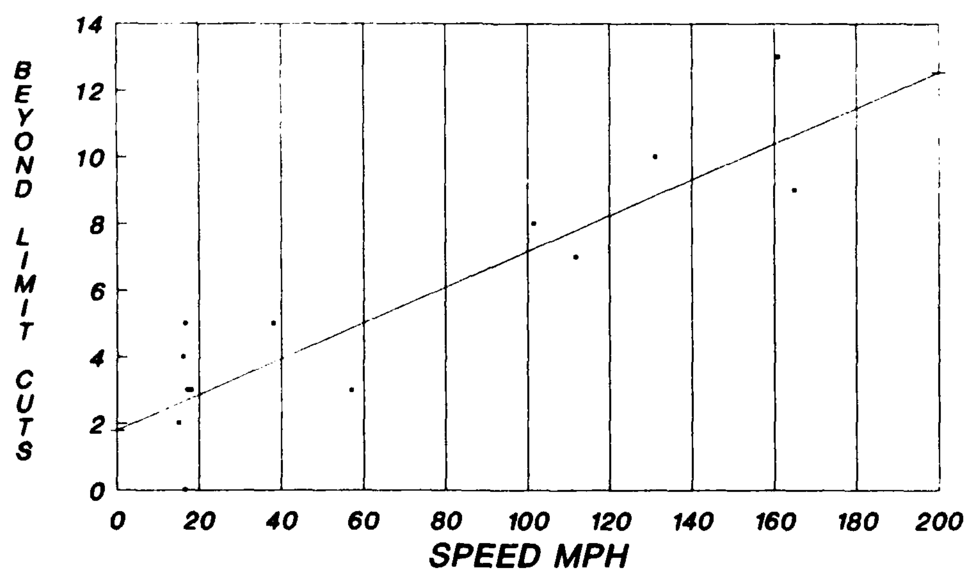


FIGURE 6 SPEED EFFECTS (OVER LIMIT CUTS)

TABLE 3 YAW EFFECTS ANALYSIS

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 +1 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 +2 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 +3 0 14300 SPEED<20 BEYOND LIMIT
QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 +4 0 14300 SPEED<20 CUT DATA

TABLE 3 YAW EFFECTS ANALYSIS
NO E1 DATA

PREPARED BY: AFWAL/FIEMB/K SCHWARTZ

FILE YAW
DATE 31-Oct Oct-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	TOTAL	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU		
J-9	24 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	4	0	14300	PAYM	2300	11.0	125	101	19	5	0	346	346	2.77	5	69.20
J-7	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	14.5	68	55	9	2	2	346	346	5.09	4	86.50
J-6	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	15.0	80	53	19	6	2	346	346	4.33	8	43.25
J-8	24 DEC 86	KS/JS	40	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	13.5	51	38	8	4	1	346	346	6.78	5	69.20
J-5	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	2	0	14300	PAYM	2300	15.0	50	38	10	1	1	346	346	6.92	2	173.00
J-11	26 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	2	0	14300	PAYM	2300	13.8	35	24	9	2	0	346	346	9.89	2	173.00
J-4	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	1	0	14300	PAYM	2300	16.0	28	22	4	2	0	346	346	12.36	2	173.00
BT-19	04 OCT 86	KS/JS	NA	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	86.50
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	115.33
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	ERR
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	41.60
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	173.00
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	115.33

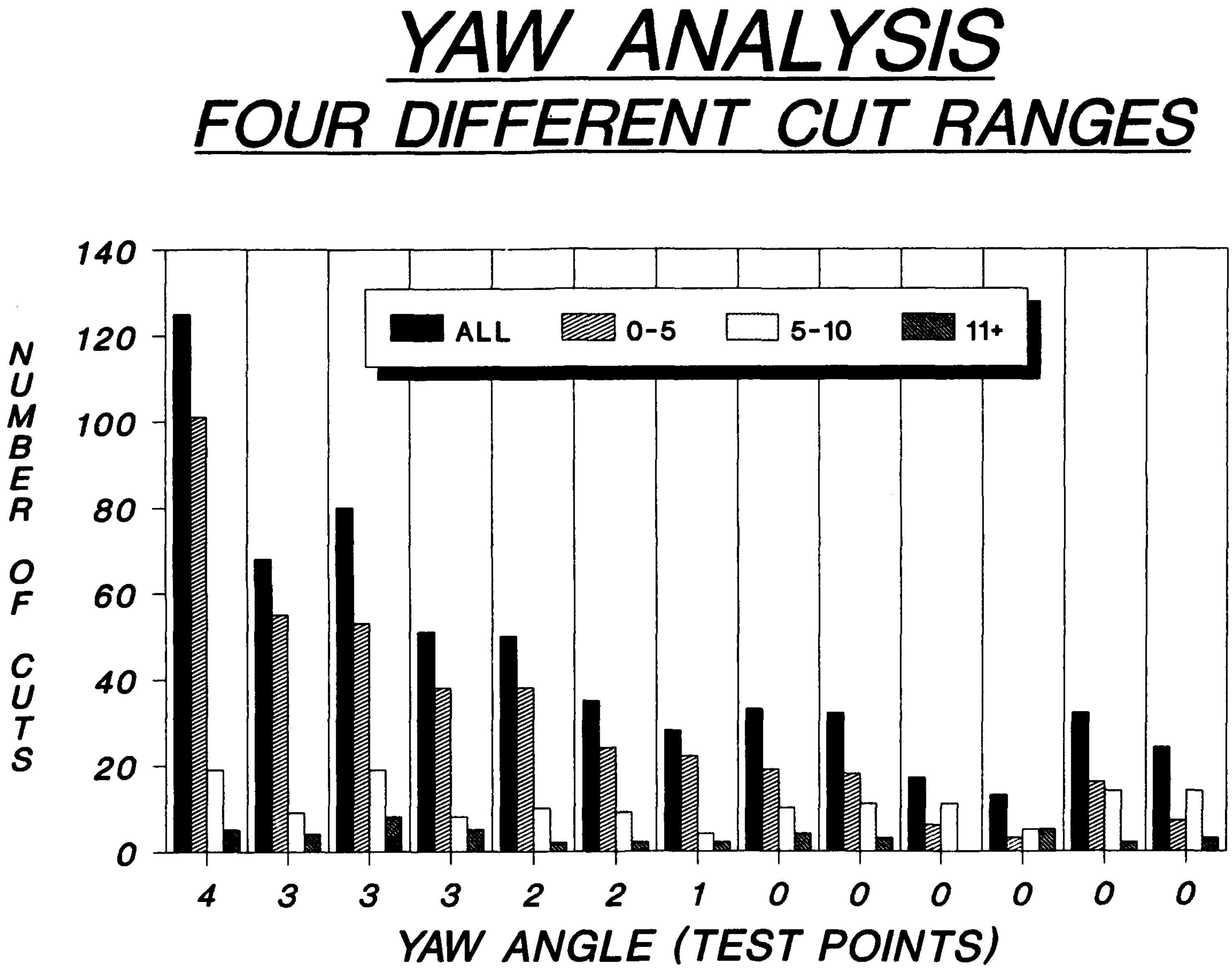


FIGURE 7 YAW ANALYSIS (4 CUT RANGES)

TABLE 4 RADIAL TIRE ANALYSIS

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 14300
QUERY CONSTANTS----------> F-16 MIC 275 DRY 1.50 0 0 0 14300 1

TABLE 4 RADIAL TIRE ANALYSIS

RADIAL TIRE ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ FILE RADIAL DATE 31-Oct Oct-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	BEYOND LIMIT CUT DATA TOTAL	BEYOND LIMIT CUT DATA ADJ HITS FOR CUT	*
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU			*
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78	11	31.45	11
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94	5	69.20	5
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.50	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	41.60	5
BT-19	04 OCT 86	KS/JS	NA	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	86.50	4
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97	3	115.33	3
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	115.33	3
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	115.33	3
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	173.00	2
H-2	14 SEP 87	JS	76	F-16	MIC	F-16R	275	8.8	6.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.5	22	13	8	1	0	346	346	15.73	9	38.44	1
H-4	14 SEP 87	JS	78	F-16	MIC	F-16R	275	8.8	6.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.5	55	38	16	1	0	346	346	6.29	17	20.35	1
H-1	14 SEP 87	JS	75	F-16	MIC	F-16R	275	8.8	6.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	16	14	1	1	0	346	346	21.63	2	173.00	1
H-3	14 SEP 87	JS	76	F-16	MIC	F-16R	275	8.8	6.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	19.0	16	9	7	0	0	346	346	21.63	7	49.43	0
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	ERR	0

* OVER 9/32

Table 4 data are graphically noted in Figure 8 where the radial design shows a marked improvement for reducing deep cuts in that all of the radial (coded MIC in Table 4) are grouped and the right low depth end of the chart. With regard to total cuts, however, no concrete conclusions can be made for the radial case.

Beyond limit cuts seemingly are greater for the radial case in that the radial limit is 5/32 versus 9/32 for the conventional bias case. No observations can be made in this area in that a detailed assessment as to limit reasons, cut locations, and true statistical trends are all required before any conclusions can be drawn.

Pressure Effects

For this survey three low pressure runs (225 psi) were conducted and compared against six operating pressure (275 psi) runs. This comparison is noted in Table 5 in two sections where both total cuts and beyond limit cuts are tabulated. A cursory review of the table does not indicate anything other than the fact that a trend may well exist for greater damage at higher pressures and should be considered in any statistical analysis work. The trend noted is presented graphically in Figure 9 where all cuts and beyond limit cuts are separately plotted at the two pressure points. Average values are also noted for each of these two cut types. Considering the average values, two trendlines are shown for all cuts and limit cuts which show a bias toward increasing probabilities of cutting at higher pressures.

Retread Tire Analysis

A total of eight retreads were compared to nine new tires and are tabulated in Table 6. The database query used to generate Table 6 did not include testbed width as a result two different testbed widths are shown. Theoretically this fact should make no difference but a preliminary analysis of Table 6 indicated that a difference does exist. To preclude any variance in this regard, a second table (Table 7) was generated to independently analyze each width. This table is presented in two sections containing data for each of the two testbed types.

In initially looking at Table 7, it would appear that little insight could be gained as to the behavior of either tire type. Assuming however, that Column AU actually represents some measure of damage resulting, a plotting of the data could be worthwhile. With this in mind, Figures 10 and 11 were generated. From these figures, a case could be made that retreaded tires do exhibit improved performance. This however is only an observation from the table and will require statistical verification.

One important additional parameter to note from these figures is the general data distribution reflecting quality of data. In both cases and with or without retreads included the quality appears excellent and conforms to classical statistical form for an expected distribution.

RADIAL TIRE ANALYSIS

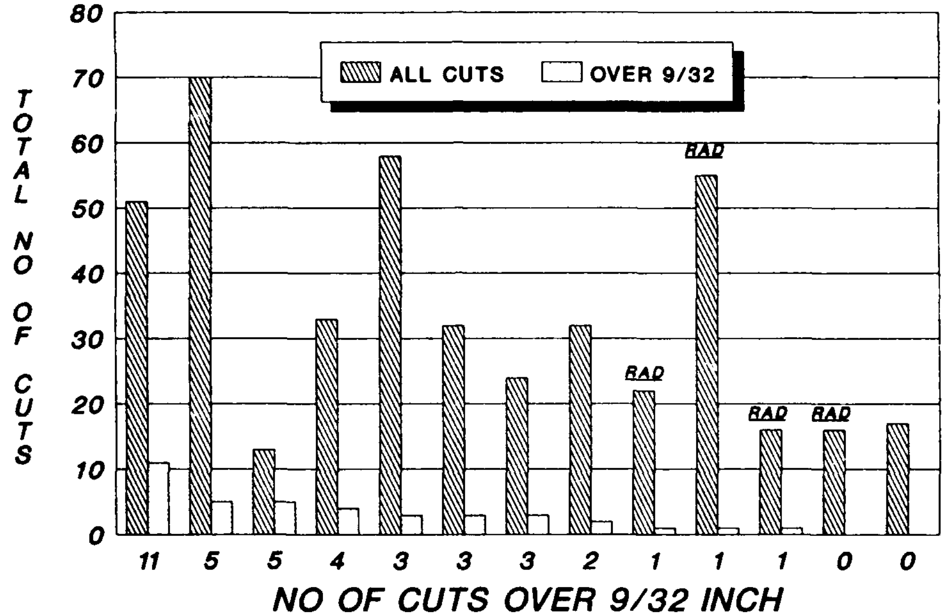


FIGURE 8 RADIAL TIRE CUT COMPARISONS

PRESSURE ANALYSIS

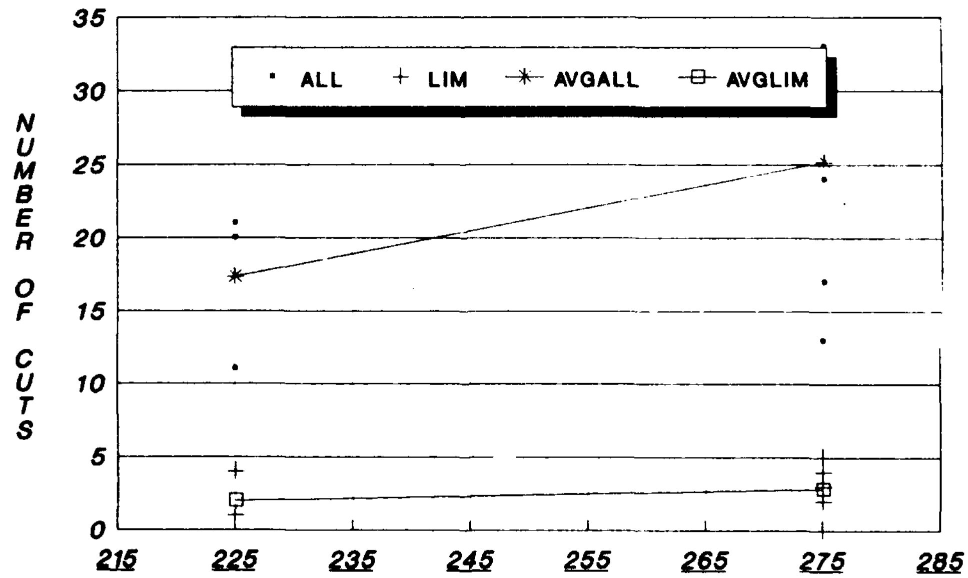


FIGURE 9 PRESSURE TREND OBSERVATIONS

TABLE 5 TIRE PRESSURE EFFECTS ANALYSIS

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 225 DRY 1.50 0 0 0 14300 SPEED<20
ERR

PRESSURE ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ

FILE PRESSURE
DATE 05-Nov Nov-91

NO E1 SERIES INCLUDED
TOTAL CUT SORT

BEYOND LIMIT CUT DATA

TEST #	DATE	ENG	AMB TEMP	A/C	MAN AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTAL CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	>10/32	ADJ--- HITS FOR TOTAL CUT
B	C	E	G	I	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU		
H-6	05 AUG 87	JS	86	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	14.0	11	6	4	1	0	346	346	31.45	1	346.00
X-7	18 JUL 86	KS/JS	85	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	41.60
D1/11	31 JUL 87	JS	78	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	ERR
H-7	06 AUG 87	JS	70	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	13.0	20	8	8	3	1	346	346	17.30	4	86.50
H-5	03 AUG 87	JS	93	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.5	21	14	6	1	0	346	346	16.48	1	346.00
D2/12	31 JUL 87	JS	82	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	115.33
D-3	03 AUG 87	JS	81	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	115.33
J-3	23 DEC 86	KS/JS	42	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	173.00
BT-19	04 OCT 86	KS/JS	7	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	86.50
						225	AVERAGE--->													2300.0	14.2	17.3	9.3	6.0	1.7	0.3			21.7	2.0	-----
						275	AVERAGE--->													2300.0	16.5	25.2	11.5	10.8	2.2	0.7			13.8	2.8	-----
LIMIT CUT SORT																															
D1/11	31 JUL 87	JS	78	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	ERR
H-5	03 AUG 87	JS	93	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.5	21	14	6	1	0	346	346	16.48	1	346.00
H-6	05 AUG 87	JS	86	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	14.0	11	6	4	1	0	346	346	31.45	1	346.00
J-3	23 DEC 86	KS/JS	42	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	173.00
D2/12	31 JUL 87	JS	82	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	115.33
D-3	03 AUG 87	JS	81	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	115.33
BT-19	04 OCT 86	KS/JS	7	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	86.50
H-7	06 AUG 87	JS	70	F-16 GY	F-16R	225	10.7	6.4	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	13.0	20	8	8	3	1	346	346	17.30	4	86.50
X-7	18 JUL 86	KS/JS	85	F-16 GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	41.60

TABLE 6 REGULAR/RETREAD COMPARISON

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 RET 275 DRY 1.50 0 0 0 14300 SPEED<20

FILE RTRDALL
TABLE 6 REG/RETREAD ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
X-11	04 OCT 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	31	13	11	7	0	346	346	11.16
X-3	18 JUL 86	KS/JS	86	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	15	5	6	4	0	208	208	13.87
D2/I2	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-10	04 OCT 86	KS/JS	80	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	24	16	4	4	0	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
X-9	21 JUL 86	KS/JS	77	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	17	7	4	4	2	346	346	20.35
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
P-13B	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	17.5	9	4	1	1	3	200	200	22.22
X-4	18 JUL 86	KS/JS	88	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.5	8	0	3	2	3	208	208	26.00
P-13A	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	9	0	0	0	14300	BUD	2300	16.5	15	5	5	5	0	400	400	26.67
X-12	04 OCT 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	6	1	2	2	1	346	346	57.67

TABLE 7 REG/RETREAD ANAL LIST CRITICAL ITEMS
CONSTANT PATTERN/EARLY PATTERN

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 6/5 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 RET 275 DRY 1.50 6/5 0 0 0 14300 SPEED<20
ERR

REG/RETREAD ANAL LIST CRITICAL ITEMS — CONSTANT PATTERN/EARLY PATTERN — PREPARED BY: AFWAL/FIEMB/K SCHWARTZ — FILE RETRD — DATE 04-Nov Nov-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU	
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94	1
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97	2
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78	3
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	5
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	6
X-11	04 OCT 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	31	13	11	7	0	346	346	11.16	7
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	8
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	9
X-12	04 OCT 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	6	1	2	2	1	346	346	57.67	10
EARLY TESTBED DATA																															
X-3	18 JUL 86	KS/JS	86	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	15	5	6	4	0	208	208	13.87	
X-10	04 OCT 86	KS/JS	80	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	24	16	4	4	0	346	346	14.42	
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	
X-9	21 JUL 86	KS/JS	77	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	17	7	4	4	2	346	346	20.35	
P-13B	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	17.5	9	4	1	1	3	200	200	22.22	
X-4	18 JUL 86	KS/JS	88	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.5	8	0	3	2	3	208	208	26.00	

45 DATA DISTRIBUTION
42 PROFILE

TIRE TYPE COMPARISON
NEW VS RETREAD (CONSTANT TESTBED)

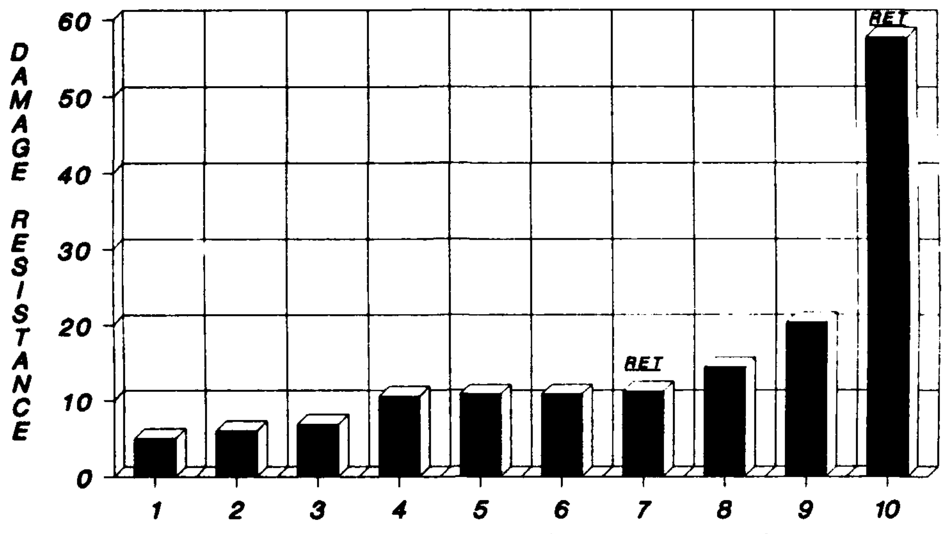


FIGURE 10 TIRE TYPE DAMAGE COMP CONST TB

TIRE TYPE COMPARISON
NEW VS RETREAD (ALL TESTBEDS)

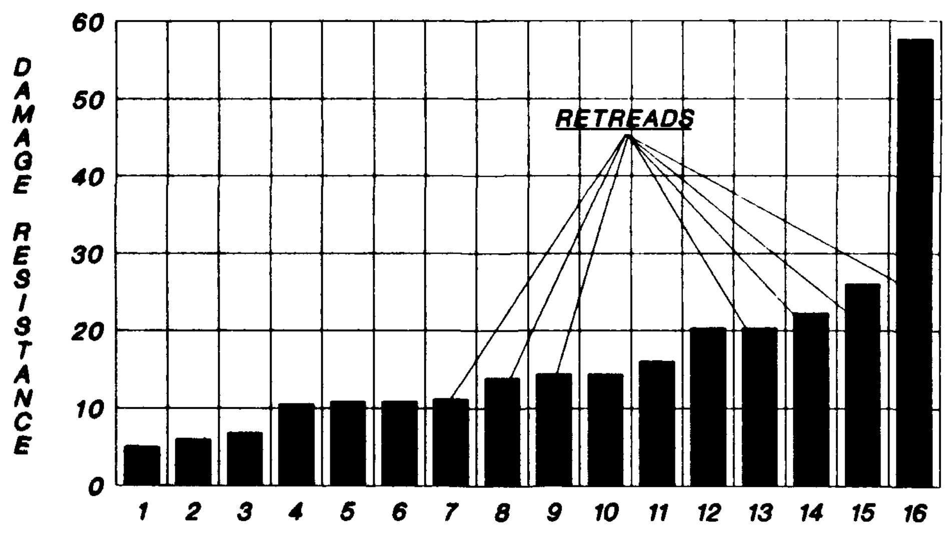


FIGURE 11 TIRE TYPE DAMAGE COMP ALL BED

Size Effects

Within the existing database, only one comparison becomes available and consists of nine F-16 main tests compared to eight F-14 nose tire tests. Any analysis of this comparison becomes difficult, however, due to other variables which are introduced. The 17 test runs are tabulated in Table 8 in descending damage order. A review of this table immediately suggests that the smaller size is vastly more damage resistant. The question that arises, however, is this improvement more an effect of size or a pressure effect.

If we go back to our pressure analysis (Table 5, Figure 9) and do a minor extrapolation back to 215 psi, which is the pressure used in the smaller sized tire, we see that tire size may well have a significant effect on damage resistance. For this earlier pressure analysis with extrapolation to 215 psi we can show an average of 15.72 total cuts or 22.01 hits to cut occurring for this case. Looking at Table 8, however, we see that damage levels on the smaller tire all fall well below this average. In fact when we combine pressure with size variance, maximum differences of up to 1700% improvement for the smaller tire can be derived. Without the luxury of further analysis in this area, little can be done other than to note the above observations. It may be that size is a highly influencing parameter or that pressure/loads effects may be far greater than projected earlier. Whatever the case further, investigations in this area would be very worthwhile.

Load Analysis

Loads effects require consideration from two significantly different points of view. If the load varies substantially, the net effect is to decrease the tire footprint width. From a tire mechanics point of view, one can consider the relationship of cut probability as a simple hit/damage relationship. From an operational point of view, however, the probability of hitting an object can be reduced substantially at lower loads in that a narrower footprint results in less area traversed during taxi/takeoff/landing/taxi segments. From this then if one were to rank test in order of severity, two distinctly different orders should result depending on if the ranking is in a form of total cutting damage or the number of hits required to generate cutting damage.

The loads survey was conducted by extracting two separate tables from the program database. The tables consist of an F-4 data analysis (Table 9) and F-16 data analysis (Table 10). Each of these tables are discussed separately in the following sections:

F-4 Loads

A total of nine tests were extracted which matched the criteria needed for this survey. However, only one of these nine represented a load different from the remaining eight. In addition the single comparative test available was from an early test vehicle trial run and no footprint data were recorded. Although little can be drawn from this data set, it has nevertheless been included as Table 9 for record purposes. About all that can be derived from this information is that the single comparative point (Item 3, Table 9) does not exhibit any significant increase or decrease in damage from either a total cut or hits to

TABLE 8 TIRE SIZE EFFECTS ANALYSIS

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 14300 1
QUERY CONSTANTS----------> F-4 215 DRY 1.50 0 0 0 4500 1
ERR FILE SIZE
SIZE ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91
PRESSURE ALSO VARIES

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
F-33	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.5	12	11	0	1	0	270	270	22.50
F-32	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.5	10	9	1	0	0	270	270	27.00
F2-10	29 JUL 86	KS/JS	86	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	5.5	3	1	2	0	0	270	270	90.00
F2-6A	28 JUL 86	KS/JS	84	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	16.5	2	1	1	0	0	270	270	135.00
F2-6	28 JUL 86	KS/JS	83	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	9.0	1	0	1	0	0	270	270	270.00
F2-9	29 JUL 86	KS/JS	82	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	8.0	1	1	0	0	0	270	270	270.00
F-31	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.0	0	0	0	0	0	270	270	
F2-5	25 JUL 86	KS/JS	82	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	19.5	0	0	0	0	0	270	270	

TABLE 9 F-4 LOADS EFFECTS ANALYSIS

QUERY CONSTANTS----------> F-4 215 DRY 1.50 0 0 0 SPEED<20
ERR
FILE F-4LOADS
F-4 LOADS ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
F-33	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.5	12	11	0	1	0	270	270	22.50
F-32	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.5	10	9	1	0	0	270	270	27.00
ST-1	12 SEP 86	KS/JS	70	F-4	BFG	F-4	215	N/A	N/A	DRY	1.50	CRL	350	4.5	5/4	0	0	0	5300	PAYM	2300	LOW	4	3	1	0	0	270	270	67.50
F2-10	29 JUL 86	KS/JS	86	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	5.5	3	1	2	0	0	270	270	90.00
F2-6A	28 JUL 86	KS/JS	84	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	16.5	2	1	1	0	0	270	270	135.00
F2-9	29 JUL 86	KS/JS	82	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	8.0	1	1	0	0	0	270	270	270.00
F2-6	28 JUL 86	KS/JS	83	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	9.0	1	0	1	0	0	270	270	270.00
F-31	11 AUG 87	JS	77	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	18.0	0	0	0	0	0	270	270	*********
F2-5	25 JUL 86	KS/JS	82	F-4	BFG	F-4	215	5.5	3.3	DRY	1.50	CRL	350	4.5	5/4	0	0	0	4500	PAYM	2300	19.5	0	0	0	0	0	270	270	*********

TABLE 10 F-16 LOADS ANAL LIST CRITICAL ITEMS

QUERY CONSTANTS----------> F-16 GY 275 DRY 1.50 0 0 0 1

FILE F-16LOAD

TABLE 10 F-16 LOADS ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
J-24	14 AUG 87	JS	77	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	7300	PAYM	2300	17.5	41	13	18	9	1	346	192	4.68
D8/J26/20	AUG 87	JS	86	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	7300	PAYM	2300	18.5	39	13	19	6	1	346	192	4.92
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
D5/18	07 AUG 87	JS	82	F-16	GY	F-16R	275	9.7	5.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	10300	PAYM	2300	14.0	31	6	14	7	4	346	269	8.68
D7/J25/20	AUG 87	JS	84	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/8	0	0	0	7300	PAYM	2300	18.5	19	6	6	7	0	346	192	10.11
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
D4/17	06 AUG 87	JS	79	F-16	GY	F-16R	275	9.7	5.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	10300	PAYM	2300	14.0	23	5	14	4	0	346	269	11.70
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35

LOAD--> 7300 10300 14300

AVERAGE NO LIMIT CUTS---------> 8.00 7.50 4.00

AVERAGE NO ALL CUTS---------> 33.00 27.00 36.67

E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
J-24	14 AUG 87	JS	77	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	7300	PAYM	2300	17.5	41	13	18	9	1	346	192	4.68
D8/J26/20	AUG 87	JS	86	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	7300	PAYM	2300	18.5	39	13	19	6	1	346	192	4.92
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D5/18	07 AUG 87	JS	82	F-16	GY	F-16R	275	9.7	5.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	10300	PAYM	2300	14.0	31	6	14	7	4	346	269	8.68
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
D4/17	06 AUG 87	JS	79	F-16	GY	F-16R	275	9.7	5.2	DRY	1.50	CRL	500	7.75	6/5	0	0	0	10300	PAYM	2300	14.0	23	5	14	4	0	346	269	11.70
D7/J25/20	AUG 87	JS	84	F-16	GY	F-16R	275	7.2	4.8	DRY	1.50	CRL	500	7.75	6/8	0	0	0	7300	PAYM	2300	18.5	19	6	6	7	0	346	192	10.11
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00

generate cut point of view.

F-16 Loads

As a result of the two points of view noted initially in this loads analysis section, Table 10 consists of two different listings to show two orders of damage. The upper table ranks the data in a hits to cut order while the lower table ranks the same data in a total cuts order. As expected two significantly different rankings do result. A quick look at both of these orders does not disclose any apparent load effect. The distribution appears totally random and will require further statistical analysis to see if any trends exist. These observations are somewhat surprising in that it was originally thought that high loads would have an observable impact.

Water Effects

Low Speed

Only one low speed water run was available and is compared against nine matching dry runs in Table 11. For this case, no conclusions or trends can be cited due to both insufficient data and the fact that the one run falls in the median of all the other data.

High Speed

For the high speed water case, two tests can be extracted and are shown in Table 12. In viewing this chart a potential trend becomes evident so a bar plot was generated covering each of the ten tests included in Table 12. This plot is noted as Figure 12 and shows that the flooded tests were the top two damage products for both all cuts and limit cut categories. In fact on an average basis, the water runs resulted in an approximate 100% increase in damage in both cases. Based on this observation, future statistical reviews should include this factor and apply this to an operational environment.

Yaw Effects (water)

A third area where water effects were investigated related to yaw where four tests are available for comparison. These tests noted in Table 13 yield a rather unexpected trend. For this case when yaw angles were introduced the level of damage was almost cut in half from a total cuts perspective. From a limit cut prospective, however, the trend is less apparent in that the one lower speed test exhibited a comparable level of damage. Because of the wide divergences in tire damage shown in Table 13, significant trends are probable and it should be verified through statistical reviews or additional testing.

Debris Size/Type

Two different debris size tables were extracted from the available data. Table 14 includes all data and Table 15 includes retread tires only. Overall damage effects are illustrated in figures 13 and 14 for all tires and retreads only. A resulting average curve is shown in both figures. All tables and curves are for F-16 main tires only and no nose tire effects were considered.

TABLE 11 LOW SPEED WATER EFFECTS (F-16)

QUERY CONSTANTS----------> F-16 GY 275 1.50 0 0 0 1

FILE WATER_LO

ERR PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

LO SPEED ONLY

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
O-1	28 SEP 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	46	23	17	5	1	346	346	7.52
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
D2/I2	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35

TABLE 12 HI SPEED WATER EFFECTS (F-16)

QUERY CONSTANTS----------> F-16 GY 275 1.50 0 0 0 14300 SPEED>20

FILE WATER_HI

ERR PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

HI SPEED ONLY

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT		
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU		
B-4	23 JUL 86	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	98.0	0	0	0	0	0	346	346	FAIL		
O-6	30 SEP 87	JS	70	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	161.4	113	31	56	20	6	346	346	3.06	1	26
O-5	29 SEP 87	JS	72	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	168.2	112	30	60	16	6	346	346	3.09	2	22
K-3	22 SEP 87	JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	160.9	68	32	23	10	3	346	346	5.09	3	13
K-1	22 SEP 87	JS	70	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	101.4	59	37	14	7	1	346	346	5.86	4	8
B-1	22 JUL 87	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	38.0	56	37	14	3	2	346	346	6.18	5	5
K-2	22 SEP 87	JS	67	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	111.7	48	33	8	6	1	346	346	7.21	6	7
K-4	23 SEP 87	JS	72	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	164.8	38	15	14	6	3	346	346	9.11	7	9
B-2	22 JUL 86	KS/JS	84	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	57.0	34	21	10	2	1	346	346	10.18	8	3
B-5	23 JUL 86	KS/JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	131.0	27	6	11	10	0	346	346	12.81	9	10
B-3	23 JUL 86	KS/JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6000	75.0	1	0	0	0	1	346	346	346.00	10	1

HI SPEED WATER EFFECTS
FLOODED RUNWAY

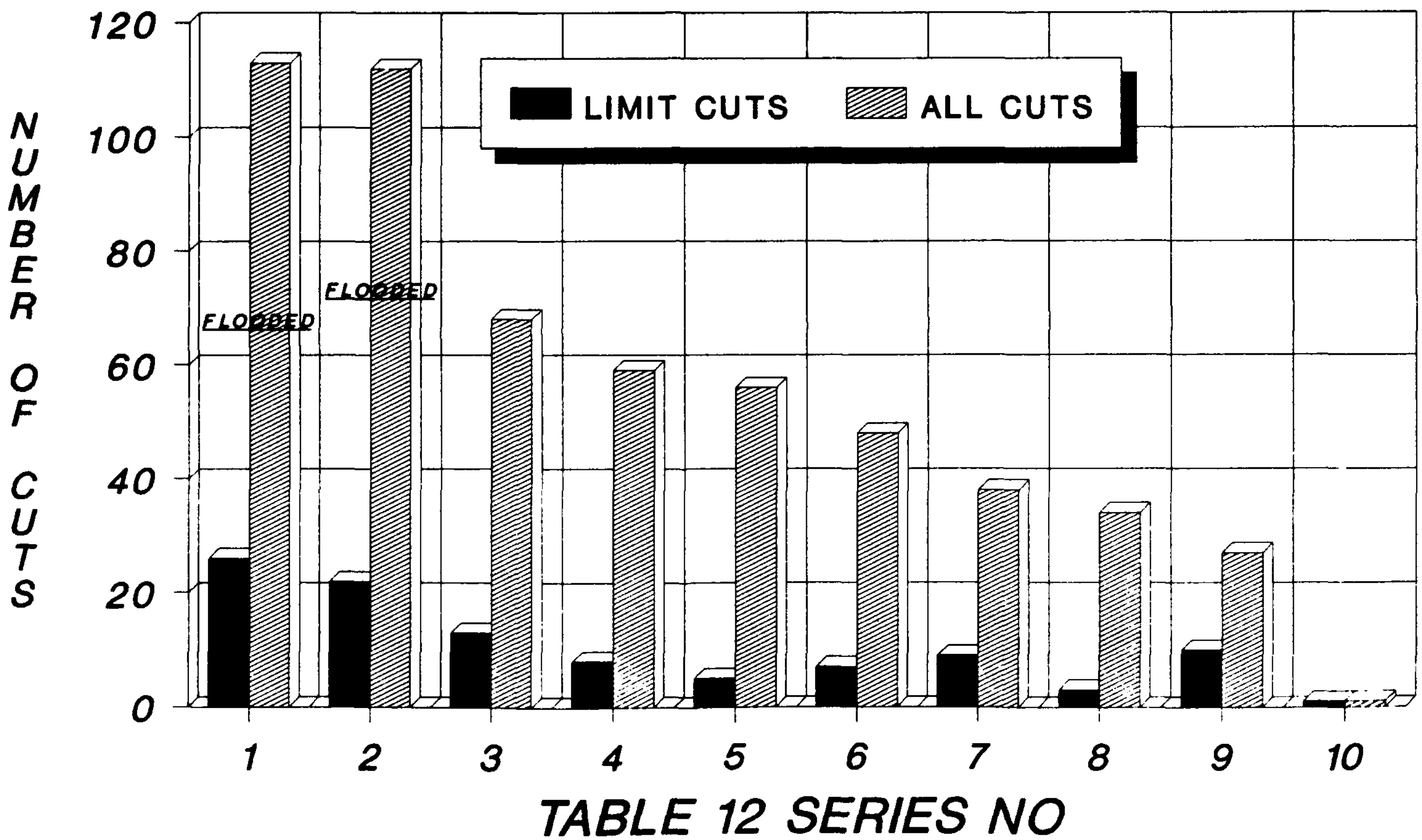


FIGURE 12 HIGH SPEED WATER COMPARISON

TABLE 13 WATER EFFECTS WITH YAW

QUERY CONSTANTS----------> F-16 GY 275 FLOD 1.50 0 0 14300 SPEED>20

WATER ANAL LIST CRITICAL ITEMS FILE WATR_YAW

ERR PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

YAW ANAL HI SPEED ONLY

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
0-6	30 SEP 87	JS	70	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	161.4	113	31	56	20	6	346	346	3.06
0-5	29 SEP 87	JS	72	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	0	0	14300	JET	6500	168.2	112	30	60	16	6	346	346	3.09
0-8	29 SEP 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	+2	0	14300	JET	6500	47.8	61	10	23	22	6	346	346	5.67
0-7	29 SEP 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	FLOD	1.50	CRL	500	7.75	6/5	0	+1	0	14300	JET	6500	160.3	59	29	22	7	1	346	346	5.86

TABLE 14 DEBRIS SIZE EFFECTS ALL DATA

QUERY CONSTANTS----------> F-16 RET 275 DRY CRL 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20
TABLE DEBRIS SIZE ANAL LIST CRITICAL ITEMS FILE DEB_SIZA
TABLE 14 DEBRIS SIZE EFFECTS ALL DATA PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct 1990
GY & RET / ALL BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
P-12	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.0	N/A	TIRE	FAILED			400	400	FAILURE
P-12A	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.5	N/A	TIRE	FAILED			400	400	FAILURE
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
P-13	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	15.0	30	14	5	5	6	200	200	6.67
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
X-11	04 OCT 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	31	13	11	7	0	346	346	11.16
X-6	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.3	17	5	6	4	2	208	208	12.24
X-3	18 JUL 86	KS/JS	86	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	15	5	6	4	0	208	208	13.87
D2/I2	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-10	04 OCT 86	KS/JS	80	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	24	16	4	4	0	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
P-10	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.0	24	4	16	2	2	400	400	16.67
X-9	21 JUL 86	KS/JS	77	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	17	7	4	4	2	346	346	20.35
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
X-8	18 JUL 86	KS/JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.1	10	6	1	3	0	208	208	20.80
P-13B	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	17.5	9	4	1	1	3	200	200	22.22
X-4	18 JUL 86	KS/JS	88	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.5	8	0	3	2	3	208	208	26.00
P-13A	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	9	0	0	0	14300	BUD	2300	16.5	15	5	5	5	0	400	400	26.67
X-5	16 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	7	3	4	0	0	208	208	29.71
X-2	16 JUL 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	10.0	7	1	3	2	1	208	208	29.71
P-11	16 MAY 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	16.5	5	3	2	0	0	200	200	40.00
X-1	16 JUL 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	5	2	1	2	0	208	208	41.60
X-2A	16 JUL 86	KS/JS	83	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	4	1	1	2	0	208	208	52.00
X-12	04 OCT 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	6	1	2	2	1	346	346	57.67
P-8	08 MAY 86	KS/DM	70	F-16	RET	F-16R	275	N/A	N/A	DRY	0.50	CRL	300	6.5	9	0	0	0	14300	BUD	2300	14.5	5	0	4	0	1	400	400	80.00

TABLE 15--DEBRIS SIZE EFFECTS (RETREAD TIRES ONLY)

QUERY CONSTANTS----------> F-16 RET 275 DRY CRL 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 RET 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20
TABLE 14 DEBRIS SIZE EFFECTS (RETREAD TIRES ONLY) FILE DEB_SIZR
DEBRIS SIZE ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91
RETREAD ONLY ALL BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU	
P-12A	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.5	N/A	TIRE	FAILED			400	400	INFIN	
P-12	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.0	N/A	TIRE	FAILED			400	400	INFIN	
P-13	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	2.00	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	15.0	30	14	5	5	6	200	200	6.67	11
X-11	04 OCT 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	31	13	11	7	0	346	346	11.16	7
X-3	18 JUL 86	KS/JS	86	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	15	5	6	4	0	208	208	13.87	4
X-10	04 OCT 86	KS/JS	80	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	24	16	4	4	0	346	346	14.42	4
P-10	08 MAY 86	KS/MS	70	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	9	0	0	0	14300	BUD	2300	15.0	24	4	16	2	2	400	400	16.67	4
X-9	21 JUL 86	KS/JS	77	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	17	7	4	4	2	346	346	20.35	6
P-13B	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	17.5	9	4	1	1	3	200	200	22.22	4
X-4	18 JUL 86	KS/JS	88	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.5	8	0	3	2	3	208	208	26.00	5
P-13A	16 MAY 86	KS/JS	72	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	300	6.5	9	0	0	0	14300	BUD	2300	16.5	15	5	5	5	0	400	400	26.67	5
X-2	16 JUL 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	10.0	7	1	3	2	1	208	208	29.71	3
P-11	16 MAY 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	BUD	2300	16.5	5	3	2	0	0	200	200	40.00	0
X-1	16 JUL 86	KS/JS	82	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	PAYM	2300	16.5	5	2	1	2	0	208	208	41.60	2
X-2A	16 JUL 86	KS/JS	83	F-16	RET	F-16R	275	N/A	N/A	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	4	1	1	2	0	208	208	52.00	2
X-12	04 OCT 86	KS/JS	78	F-16	RET	F-16R	275	N/A	N/A	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	6	1	2	2	1	346	346	57.67	3
P-8	08 MAY 86	KS/DM	70	F-16	RET	F-16R	275	N/A	N/A	DRY	0.50	CRL	300	6.5	9	0	0	0	14300	BUD	2300	14.5	5	0	4	0	1	400	400	80.00	1

DEBRIS SIZE COMPARISON
ALL TIRE TYPES

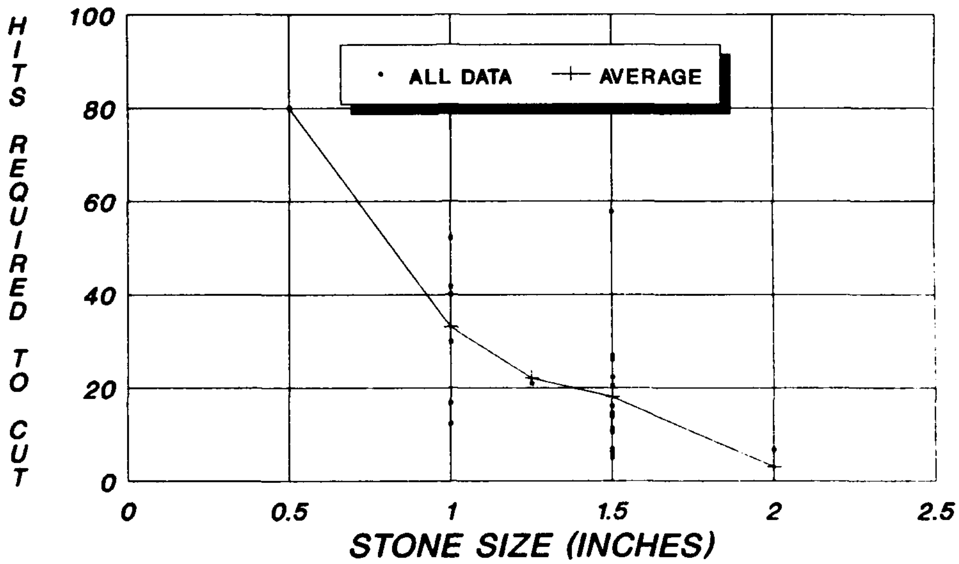


FIG 13 DEB SIZE EFFECTS (ALL TIRE TYPES)

DEBRIS SIZE COMPARISON
RETREAD TIRES ONLY

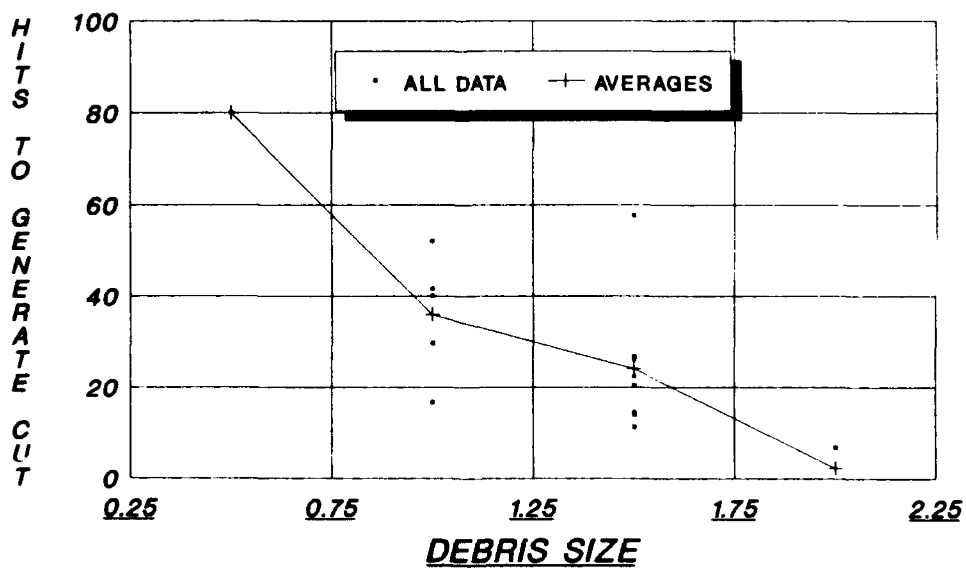


FIG 14 DEB SIZE EFFECTS (RETREAD ONLY)

The results are as expected with larger debris causing a greater level of damage. Effects appear to be fairly linear with a stone size of 1.5 to 2.0 inches becoming a limiting size. As noted in Table 14, two of the three 2-inch runs resulted in tire blowouts. Through observation of these two failed runs it is estimated that failure occurred at 10% and 50% into the testbeds for tests P-12 and P-12A respectively. Although no 1.5-inch failures are noted in these tables, it should be noted that at least one such failure did occur with the introduction of a braking variable.

With regard to larger cuts, some additional analysis was done. Figure 15 shows the results of extracting all of the cuts over 10/32 inch deep from Table 15. Although a similar trend exists, it may be that at larger diameters, the trend becomes increasingly nonlinear.

Within the test effort, shrapnel tests became a problem due to a limited availability of uniform sized shrapnel for use. It was possible, however, to obtain about 250 pieces of uniform sized shrapnel representing a 1.25-inch stone comparison. Four tests were then conducted utilizing this debris on a 250-ft testbed. These results could then be compared to 12 stone runs involving a 1.50-in stone size. The results of this comparison are presented in Table 16 in increasing order of damage. Table 16 data can be assessed in two ways, either as it stands or by application of the size effects data noted in Figures 13 and 14. As the data stands, an argument exists for higher levels of damage with shrapnel, because in general the shrapnel runs fall into the upper 50 percentile of the data. However, if size effects are applied, an even greater level of damage can be noted. More specifically from Tables 10 and 11, an approximate 1/3 reduction in damage can be realized in going from a 1.5 to a 1.25-inch size or a 150% increase for the larger size. Introducing these adjustments into the Table 16 data, it can be seen that of all tests falling into the upper 31 percentile of damage, four of them are shrapnel runs.

For the larger cut case, a second table (Table 17) is presented with a new column added. This column adjusts large cut data for both size and testbed length and presents it in order of increasing damage. Size effects adjustments were made based on the Figure 15 nonlinear size effects for deep cutting. Overall the results for large cuts are similar to the previous findings for all cuts. Two runs comprising the upper 12.5 percentile were both shrapnel. Out of the eight runs comprising the upper 50 percentile, 50% were shrapnel, and of the eight runs comprising the lower 50 percentile, none were shrapnel.

Results of both the total cuts and deep cuts data are presented graphically in Figures 16 and 17. Figure 16 presents both adjusted and unadjusted results while Figure 17 is only the size adjusted data.

Braking Analysis

A total of 17 tests were available for the braking analysis and are presented in Tables 18, 18a, 19 and 19a. Twelve of these points, however, are 0 psi baseline points, so any statistical conclusions in this area will be difficult.

The reason for the limited number of positive pressure tests can be attributed

DEBRIS SIZE COMPARISON

RETREAD TIRES ONLY

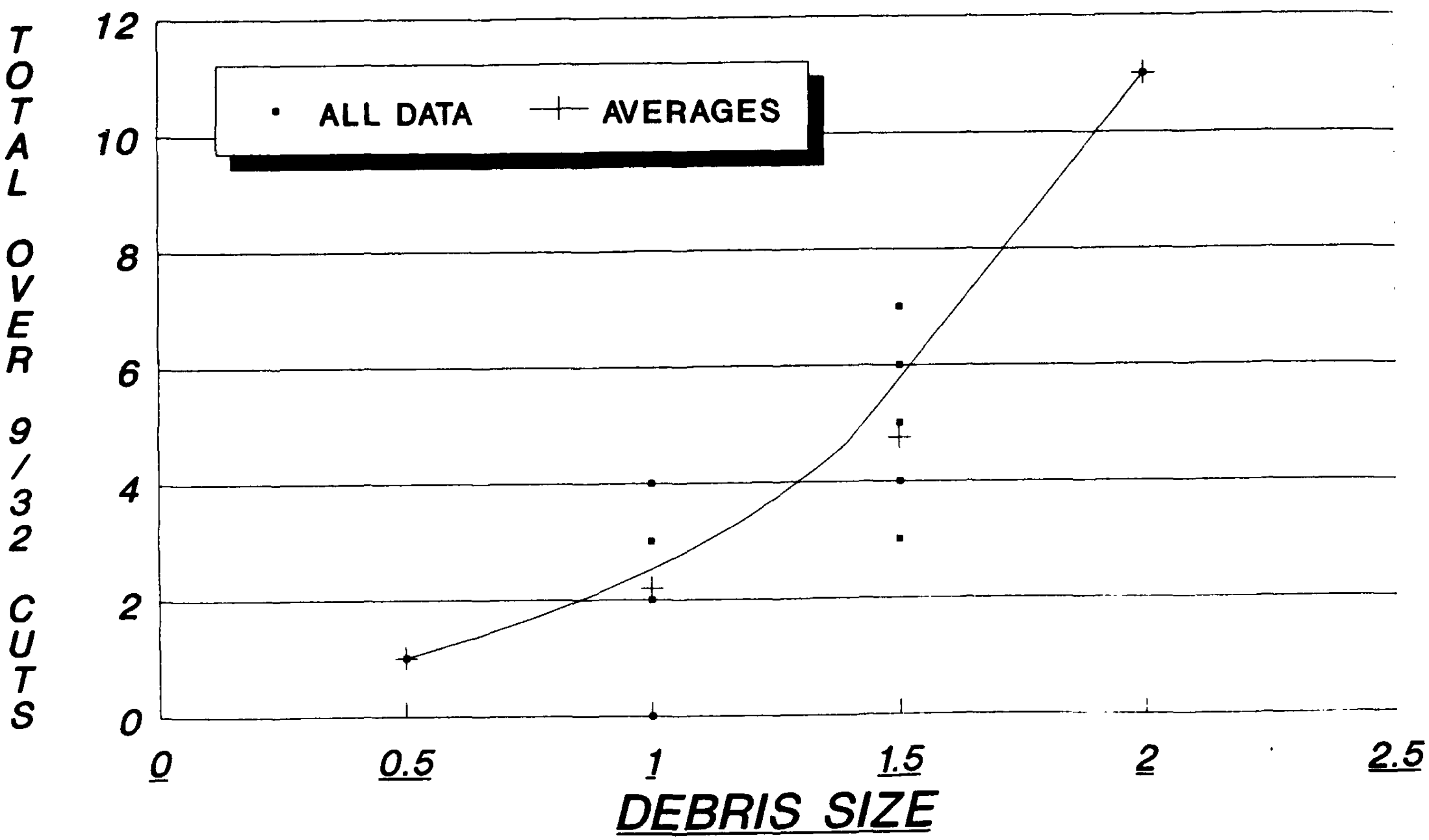


FIG 15 DEBRIS SIZE EFFECTS (DEEP CUTS)

TABLE 16 DEBRIS TYPE ANAL LIST CRITICAL ITEMS

QUERY CONSTANTS----------> F-16 GY 275 DRY SHRAP 0 0 0 14300 SPEED<20

QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20

FILE SHRAP

PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

ERR

GY ONLY ALL BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT		
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU		
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94	1	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97	2	5.97
C-3A	11 SEP 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.5	29	11	13	3	2	173	173	5.97	3	3.94
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78	4	6.78
C-1	11 SEP 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.0	20	6	11	3	0	173	173	8.65	5	5.71
C-4A	11 SEP 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.0	18	10	7	0	1	173	173	9.61	6	6.34
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	7	10.48
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	8	10.81
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	9	10.81
X-6	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.3	17	5	6	4	2	208	208	12.24	10	12.24
C-2	11 SEP 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.5	14	6	7	0	1	173	173	12.36	11	8.15
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	12	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	13	16.00
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	14	20.35
X-8	18 JUL 86	KS/JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.1	10	6	1	3	0	208	208	20.80	15	20.80
X-5	16 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	7	3	4	0	0	208	208	29.71	16	29.71

TABLE 17 DEBRIS TYPE ANAL LIST CRITICAL ITEMS
GY ONLY ALL BEDS (DEEP CUTS ADJUSTED)

QUERY CONSTANTS----------> F-16 GY 275 DRY SHRAP 0 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20

FILE SHRAP1

ERR PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 04-Nov Nov-91

GY ONLY ALL BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT		
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU	XX	
C-3A	11 SEP 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.5	29	11	13	3	2	173	173	5.97	22	1
C-1	11 SEP 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.0	20	6	11	3	0	173	173	8.65	14	2
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78	11	3
X-6	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.3	17	5	6	4	2	208	208	12.24	6	4
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94	5	5
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00	5	6
C-2	11 SEP 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.5	14	6	7	0	1	173	173	12.36	4.1	7
C-4A	11 SEP 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	SHRAP	250	7.75	6/5	0	0	0	14300	PAYM	2300	19.0	18	10	7	0	1	173	173	9.61	4.1	8
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	4	9
X-8	18 JUL 86	KS/JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.1	10	6	1	3	0	208	208	20.80	3	10
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	3	11
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	3	12
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97	3	13
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	2	14
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	0	15
X-5	16 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	7	3	4	0	0	208	208	29.71	0	16

DEBRIS TYPE EFFECTS
REG & ADJUSTED

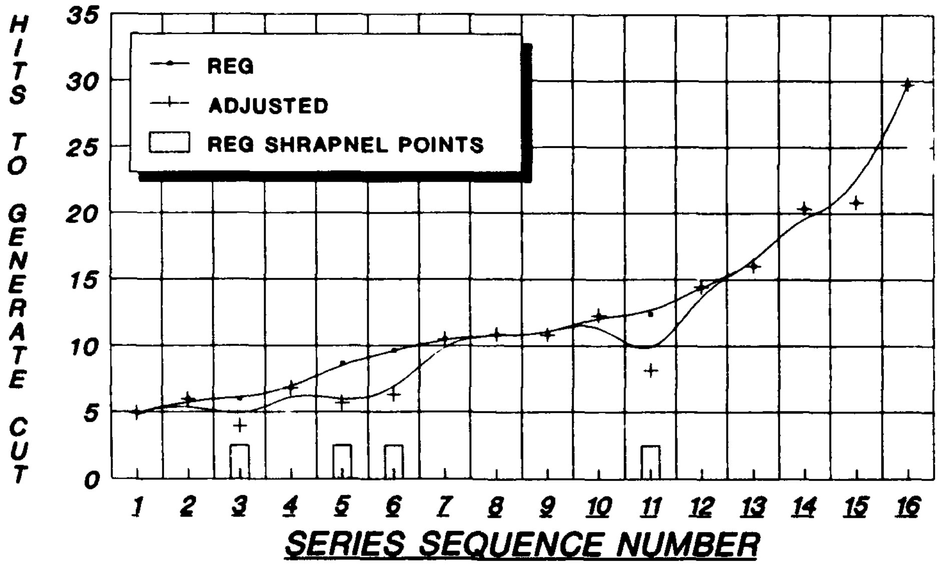


FIG 16 TYPE EFFECTS (AS IS WITH ADJ)

DEBRIS TYPE EFFECTS
GY ONLY ALL BEDS (SIZE ADJUSTED)

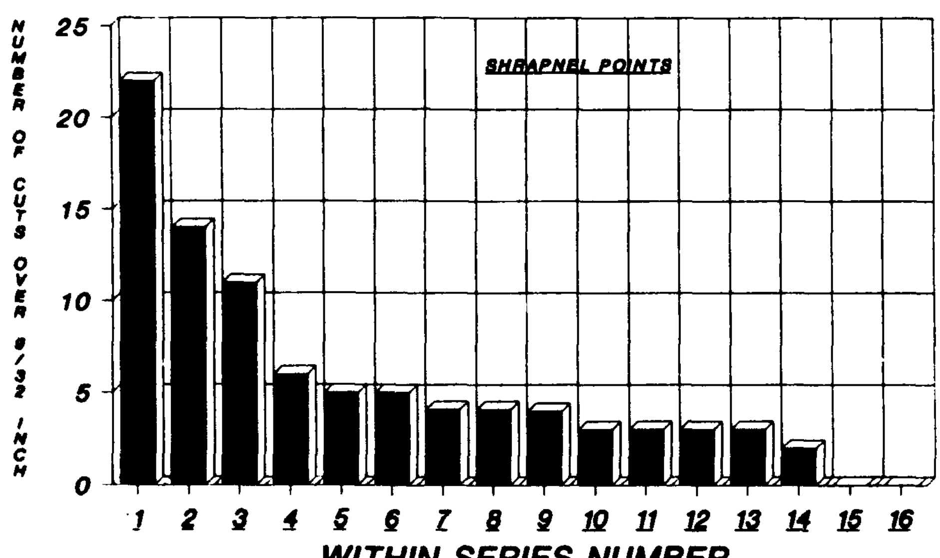


FIG 17 DEB TYPE EFFECTS-DEEP CUTS-SZ ADJ

TABLE 18 BRAKING ANAL LIST CRITICAL ITEMS
(GY ONLY ALL SIZE BEDS)

QUERY CONSTANTS----------> F-16 GY 275 DRY BRAKE 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20

FILE BRAKE17
TABLE 18 BRAKING ANAL LIST CRITICAL ITEMS PREPARED BY: WRDC/FIVMB/K SCHWARTZ DATE 31-Oct Oct-91
GY ONLY ALL SIZE BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
BT-17	04 OCT 86	KS/JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	1040	0	0	14300	PAYM	2300	16.0	67	38	16	12	1	346	346	5.16
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
I-3	03 AUG 87	JS	87	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	17.0	29	11	15	2	1	346	346	11.93
I-4	04 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	18.0	29	14	10	4	1	346	346	11.93
X-6	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.3	17	5	6	4	2	208	208	12.24
I-5	30 JUL 87	JS	91	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	14.0	26	15	6	5	0	346	346	13.31
D2/I2	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
I-6	03 AUG 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	10.3	22	8	11	3	0	346	346	15.73
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
X-8	18 JUL 86	KS/JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.1	10	6	1	3	0	208	208	20.80
X-5	16 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	7	3	4	0	0	208	208	29.71

TABLE 18a BRAKING ANAL--LIMIT CUT DATA (ALL STONES & 1.5 DIA STONES)

ADJ HIT	ADJ HITS FOR CUT	1.5 CUTS ZERO	ALL CUTS ZERO	ALL CUTS 200	ALL CUTS 500	ALL CUTS 1050		LIM
AS	AU							
346	4.94	4.94	4.94				13.61	5
346	5.16					5.16	5.16	13
346	5.97	5.97	5.97				13.61	3
346	6.78	6.78	6.78				13.61	11
346	10.48	10.48	10.48				13.61	4
346	10.81	10.81	10.81				13.61	3
346	10.81	10.81	10.81				13.61	2
346	11.93			11.93			11.93	3
346	11.93			11.93			11.93	5
208	12.24		12.24				13.61	6
346	13.31				13.31		14.52	5
346	14.42	14.42	14.42				13.61	3
346	15.73				15.73		14.52	3
208	16.00		16.00				13.61	5
346	20.35	20.35	20.35				13.61	0
208	20.80		20.80				13.61	3
208	29.71		29.71				13.61	0
	AVG-->	10.57	13.61	11.93	14.52	5.16		

TEST		LIMIT ADJ HITS TO CUT	AVGS	1.5 IN LIMIT ADJ HITS TO CUT	AVGS
J-3	0	173.0		173.0	
X-8	0	69.3			
X-5	0	0.0			
E1-2	0	69.2		69.2	
E1-1	0	31.5		31.5	
X-6	0	34.7			
D-3	0	115.3		115.3	
D1/I1	0	0.0		0.0	
E1-4	0	115.3		115.3	
X-7	0	41.6			
BT-19	0	86.5		86.5	
D2/I2	0	115.3	70.9	115.3	88.26
I-4	200	69.2		69.2	
I-3	200	115.3	92.2	115.3	92.26
I-6	500	115.3		115.3	
I-5	500	69.2	92.2	69.2	92.26
BT-17	1040	26.6	26.6	26.6	26.61

TABLE 19--BRAKING ANAL LIST CRITICAL ITEMS
(GY ONLY 6/4 BEDS)

QUERY CONSTANTS----------> F-16 GY 275 DRY 6/5 BRAKE 0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 6/5 0 0 0 14300 0 0 SPEED<20

FILE BRAKING1

TABLE 19--BRAKING ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91
GY ONLY 6/4 BEDS

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
BT-17	04 OCT 86	KS/JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	1040	0	0	14300	PAYM	2300	16.0	67	38	16	12	1	346	346	5.16
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
I 3	03 AUG 87	JS	87	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	17.0	29	11	15	2	1	346	346	11.93
I-4	04 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	18.0	29	14	10	4	1	346	346	11.93
I-5	30 JUL 87	JS	91	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	14.0	26	15	6	5	0	346	346	13.31
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
I-6	03 AUG 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	10.3	22	8	11	3	0	346	346	15.73
D1/I1	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35

TABLE 19a BRAKE PRESSURE/DRAG RELATIONSHIP

BRAKE PRESS	AVERAGE OF PEAK DRAG	AVAVERAGE OF MEAN DRAG
0	1321	142
200	1729	522
500	1979	1085
1000	3770	2751

to difficulties encountered in the brake control system and the non-representative mass of the test vehicle. For the F-16 aircraft, two brakes are utilized to arrest a 25,000 to 35,000 pound vehicle. In the test setup, however, a single brake is utilized to arrest a mass of 50,000 to 60,000 lbs or almost four times the real requirement.

For the test itself, only a comparative attempt was introduced whereby various brake pressures were applied just prior to testbed entry and released at testbed exit. This requirement in conjunction with a poor brake control system setup resulted in questionable brake pressure values. A number of trail tests were conducted noting deceleration and testbed speed behavior, and it was concluded that brake pressure values could be off as much as 175 psi. To help offset this fact, loads data was analyzed to note drag effects as related to brake pressure. The objective here is to make drag rather than pressure an available comparison for anticipated future statistical studies. A summary of this drag analysis is noted in Table 19a where the average of all tests for peak and mean drag values were computed. A limited analysis of the Table 18 and 19 data was conducted in this report and is summarized in Figures 18 and 19. The results presented represent all cuts and no conclusive trend becomes apparent although one might conclude that at drag loads above 1100 lbs significantly increased cutting does result. For beyond limit cuts it was originally thought that a significant trend would result toward more cuts and higher braking. However, as Figure 19 illustrates limit cuts seem to hold constant up to some value beyond 500 psi (approx. 1100 lbs drag) at which point original thinking may hold true. Table 19 data for only 1.5 in debris have been included on Figure 18. For this case, a trend toward reduced cutting up to 500 psi brake pressure exists followed by increased cutting beyond 500 psi.

Considering the previously noted trends several notes of caution are in order. First the potential + 175 psi pressure scatter has not been factored into any data and should be considered in any future analysis. Also the amount of data generated at certain points may or may not hold statistical significance and must be considered accordingly in anticipated future statistical studies. Finally future tire cutting T&E programs should include further braking runs to permit firm conclusions to be drawn in the area.

Combined Braking/Yaw

Data for a combined braking/yaw trend analysis was extracted and is presented in Tables 20, 21, and 22. Data points are noted graphically in figures 20 and 21. From these figures, the effects of increasing damage at higher yaw angles is apparent, with 30-50% reductions being noted with the addition of braking. This fact reinforces the findings of the previous section in that braking may not be as critical as originally anticipated. The fact that braking may serve to actually reduce damage could well be true in that theories can be offered as to why this might occur. Typical theories might include localized heating effects or a tendency for the tire to generate a rolling effect on debris when encountered. It should also be noted that these effects apply only to the 200 and 500 psi values tested and for hard braking, the resulting trend may well reverse itself. Several potential trends can be noted from the data; however, additional testing with a refined brake control system will be required if a firm grasp of these effects is to be attained.

BRAKING EFFECTS
ALL BEDS GY ONLY

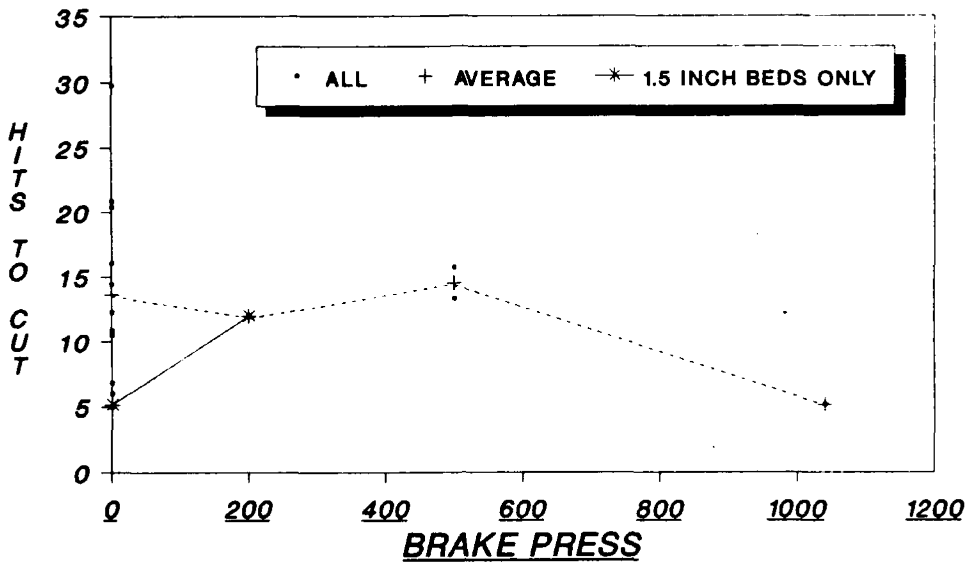


FIG 18 BRAKE PRESS EFFECTS-- ALL CUTS

BRAKE PRESSURE EFFECTS
LIMIT CUTS

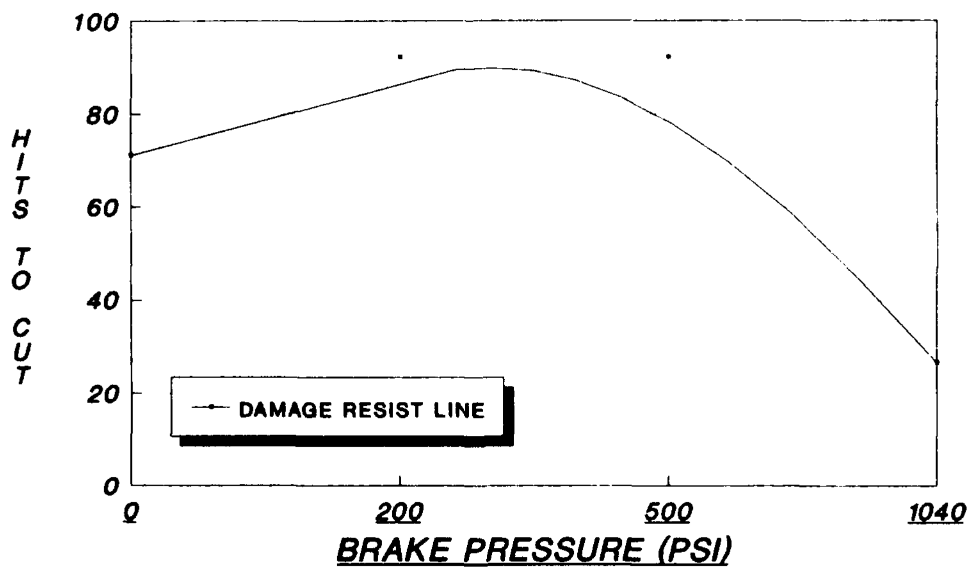


FIG-19 BRAKE PRESS EFFECTS--LIMIT CUTS

TABLE 20 COMBINED BRAKING/YAW ANAL LIST CRITICAL ITEMS
(GY 6/4 BEDS INC POS PRESSURE ONLY)

QUERY CONSTANTS----------> F-16 GY 275 DRY 6/5 BRAKE 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 6/5 BRAKE 0 14300 0 0 SPEED<20

FILE COMBO_BR

TABLE 20 COMBINED BRAKING/YAW ANAL LIST CRITICAL PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91

GY 6/4 BEDS INC POS PRESSURE ONLY COMBO_BR

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	CAM YAW		VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT				
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU	0 DEG	1 DEG	3 DEG	
BT-17	04 OCT 86	KS/JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	1040	0	0	14300	PAYM	2300	16.0	67	38	16	12	1	346	346	5.16	5.16			11.61
J-19	05 AUG 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	3	0	14300	PAYM	2300	3.8	56	24	23	9	0	346	346	6.18			6.18	6.92
J-28	04 AUG 87	JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	3	0	14300	PAYM	2300	3.0	51	27	16	8	0	346	346	6.78			6.78	6.92
J-16	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	3	0	14300	PAYM	2300	10.5	49	21	20	6	2	346	346	7.06			7.06	6.92
J-18	04 AUG 87	JS	94	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	3	0	14300	PAYM	2300	1.0	48	26	17	4	1	346	346	7.21			7.21	6.92
J-17	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	3	0	14300	PAYM	2300	5.0	47	20	21	3	3	346	346	7.36			7.36	6.92
J-15	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	1	0	14300	PAYM	2300	7.5	36	15	14	6	1	346	346	9.61		9.61		11.34
J-12	05 AUG 87	JS	88	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	1	0	14300	PAYM	2300	11.3	35	17	12	6	0	346	346	9.89		9.89		11.34
J-14	05 AUG 87	JS	92	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	1	0	14300	PAYM	2300	10.5	32	12	17	3	0	346	346	10.81		10.81		11.34
I-4	04 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	18.0	29	14	10	4	1	346	346	11.93	11.93			11.61
I-3	03 AUG 87	JS	87	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	17.0	29	11	15	2	1	346	346	11.93	11.93			11.61
I-5	30 JUL 87	JS	91	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	14.0	26	15	6	5	0	346	346	13.31	13.31			11.61
J-13	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	1	0	14300	PAYM	2300	12.5	23	12	6	5	0	346	346	15.04		15.04		11.34
I-6	03 AUG 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	10.3	22	8	11	3	0	346	346	15.73	15.73			11.61

TABLE 21 COMBINED BRAKE/YAW (ALL BRAKE PRESSURES INCLUDED)

QUERY CONSTANTS----------> F-16 GY 275 DRY 6/5 BRAKE>0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 6/5 0 0 14300 0 0 SPEED<20
TABLE 21 COMBINED BRAKE/YAW (ALL BRAKE PRESSURES INCLUDED) FILE COMBO
PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91

GY 6/4 BEDS INC ZERO B PRESSURE

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
J-9	24 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+4	0	14300	PAYM	2300	11.0	125	101	19	5	0	346	346	2.77
J-6	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+3	0	14300	PAYM	2300	15.0	80	53	19	6	2	346	346	4.33
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
J-7	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+3	0	14300	PAYM	2300	14.5	68	55	9	2	2	346	346	5.09
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
J-19	05 AUG 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	+3	0	14300	PAYM	2300	3.8	56	24	23	9	0	346	346	6.18
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
J-8	24 DEC 86	KS/JS	40	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+3	0	14300	PAYM	2300	13.5	51	38	8	4	1	346	346	6.78
J-5	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+2	0	14300	PAYM	2300	15.0	50	38	10	1	1	346	346	6.92
J-16	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	+3	0	14300	PAYM	2300	10.5	49	21	20	6	2	346	346	7.06
J-18	04 AUG 87	JS	94	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	+3	0	14300	PAYM	2300	1.0	48	26	17	4	1	346	346	7.21
J-17	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	+3	0	14300	PAYM	2300	5.0	47	20	21	3	3	346	346	7.36
J-15	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	+1	0	14300	PAYM	2300	7.5	36	15	14	6	1	346	346	9.61
J-12	05 AUG 87	JS	88	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	+1	0	14300	PAYM	2300	11.3	35	17	12	6	0	346	346	9.89
J-11	26 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+2	0	14300	PAYM	2300	13.8	35	24	9	2	0	346	346	9.89
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
J-14	05 AUG 87	JS	92	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	+1	0	14300	PAYM	2300	10.5	32	12	17	3	0	346	346	10.81
I-4	04 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	18.0	29	14	10	4	1	346	346	11.93
I-3	03 AUG 87	JS	87	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	17.0	29	11	15	2	1	346	346	11.93
J-4	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	+1	0	14300	PAYM	2300	16.0	28	22	4	2	0	346	346	12.36
I-5	30 JUL 87	JS	91	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	14.0	26	15	6	5	0	346	346	13.31
J-2	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	-1	0	14300	PAYM	2300	16.5	25	23	2	0	0	346	346	13.84
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
J-13	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	+1	0	14300	PAYM	2300	12.5	23	12	6	5	0	346	346	15.04
I-6	03 AUG 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	10.3	22	8	11	3	0	346	346	15.73
J-1	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	-2	0	14300	PAYM	2300	11.1	18	15	3	0	0	346	346	19.22
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35

TABLE 22 BRAKING/YAW ANALYSIS (POS BRAKE/0 BRAKE COMPARISON)

QUERY CONSTANTS----------> F-16 GY 275 DRY 6/5 BRAKE>0 0 14300 SPEED<20
QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 6/5 0 0 14300 0 0 SPEED<20
TABLE 22 BRAKING/YAW ANALYSIS (POS BRAKE/0 BRAKE COMPARISON) FILE COMBOA
TABLE COMBINED BRAKING/YAW ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91
GY 6/4 BEDS INC ZERO B PRESSURE

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FOR CUT	
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU	
ZERO BRAKE PRESSURE																															
J-1	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	-2	0	14300	PAYM	2300	11.1	18	15	3	0	0	346	346	19.22	
J-2	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	-1	0	14300	PAYM	2300	16.5	25	23	2	0	0	346	346	13.84	
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42	13.31
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35	11.93
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94	11.93
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97	15.73
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78	
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81	
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81	
BT-19	04 OCT 86	KS/JS	N/A	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48	
J-4	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	1	0	14300	PAYM	2300	16.0	28	22	4	2	0	346	346	12.36	11.91
J-11	26 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	2	0	14300	PAYM	2300	13.8	35	24	9	2	0	346	346	9.89	
J-5	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	2	0	14300	PAYM	2300	15.0	50	38	10	1	1	346	346	6.92	
J-8	24 DEC 86	KS/JS	40	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	13.5	51	38	8	4	1	346	346	6.78	7.21
J-6	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	15.0	80	53	19	6	2	346	346	4.33	6.18
J-7	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	3	0	14300	PAYM	2300	14.5	68	55	9	2	2	346	346	5.09	7.06
J-9	24 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	4	0	14300	PAYM	2300	11.0	125	101	19	5	0	346	346	2.77	
POSITIVE BRAKE PRESSURE																															
I-5	30 JUL 87	JS	91	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	14.0	26	15	6	5	0	346	346	13.31	
I-4	04 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	18.0	29	14	10	4	1	346	346	11.93	
I-3	03 AUG 87	JS	87	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	0	0	14300	PAYM	2300	17.0	29	11	15	2	1	346	346	11.93	
I-6	03 AUG 87	JS	80	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	500	0	0	14300	PAYM	2300	10.3	22	8	11	3	0	346	346	15.73	
J-14	05 AUG 87	JS	92	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	1	0	14300	PAYM	2300	10.5	32	12	17	3	0	346	346	10.81	
J-13	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	1	0	14300	PAYM	2300	12.5	23	12	6	5	0	346	346	15.04	
J-12	05 AUG 87	JS	88	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	1	0	14300	PAYM	2300	11.3	35	17	12	6	0	346	346	9.89	
J-15	05 AUG 87	JS	90	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	1	0	14300	PAYM	2300	7.5	36	15	14	6	1	346	346	9.61	
J-18	04 AUG 87	JS	94	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	3	0	14300	PAYM	2300	1.0	48	26	17	4	1	346	346	7.21	
J-19	05 AUG 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	400	3	0	14300	PAYM	2300	3.8	56	24	23	9	0	346	346	6.18	
J-16	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	3	0	14300	PAYM	2300	10.5	49	21	20	6	2	346	346	7.06	
J-17	04 AUG 87	JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	200	3	0	14300	PAYM	2300	5.0	47	20	21	3	3	346	346	7.36	

COMBINED BRAKE AND YAW

DATA PER COMBOA FILE

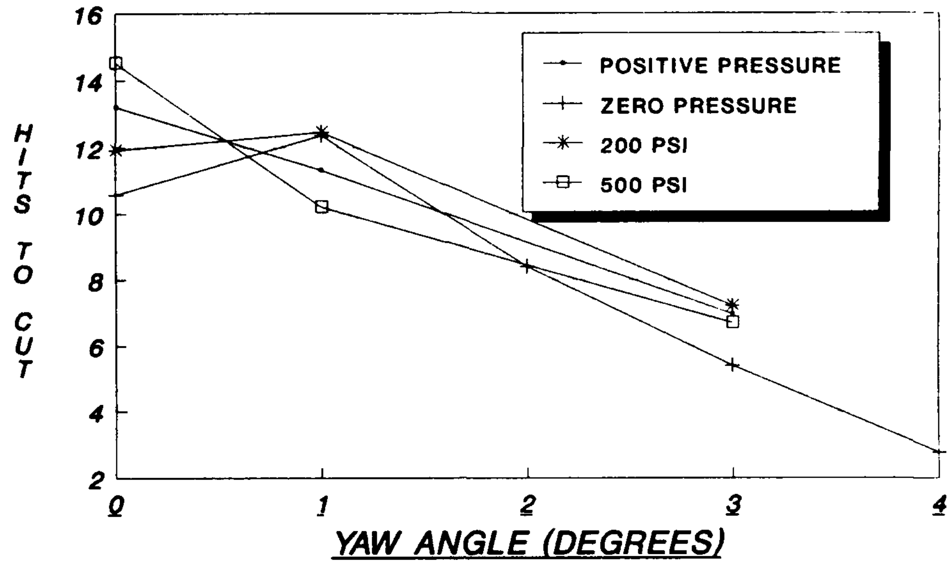


FIG-20 COMB BRAKE YAW DATA--ALL CUTS

YAW EFFECTS AND BRAKING

VARYING BRAKE PRESS NOTED AT DATA POINT

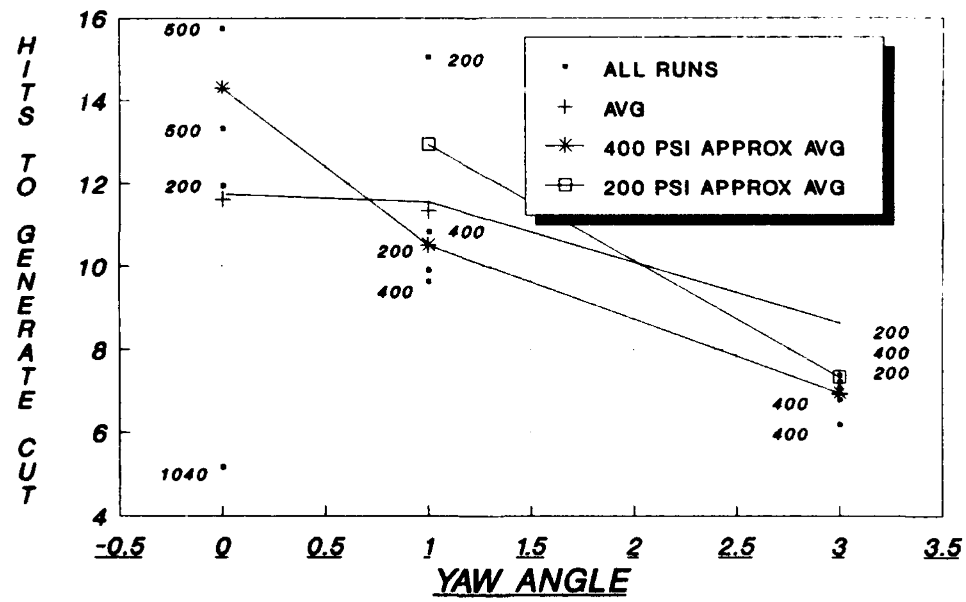


FIG 21 AVERAGED BRAKE YAW DATA

A second analysis was also conducted relative to limit cuts only and is graphically illustrated in Figure 22. For the limit case, the addition of braking behaves as expected when the fitted trend lines are compared. More specifically an increase in damage of from 50% and 0 degree yaw to 60% at 3 degree yaw can be derived. Increasing damage at higher yaw angles with braking is also confirmed.

Distribution Analysis

An attempt was made at a limited distribution survey to see if any effects were apparent. The results of this data base extraction are noted in Table 23. In reviewing this table, no apparent effects could be noted since only one test at the same stone size with a nonstandard distribution was found. Data for this test does fall near the edge of the expected range; however, it is still within an expected value and no conclusions can be made.

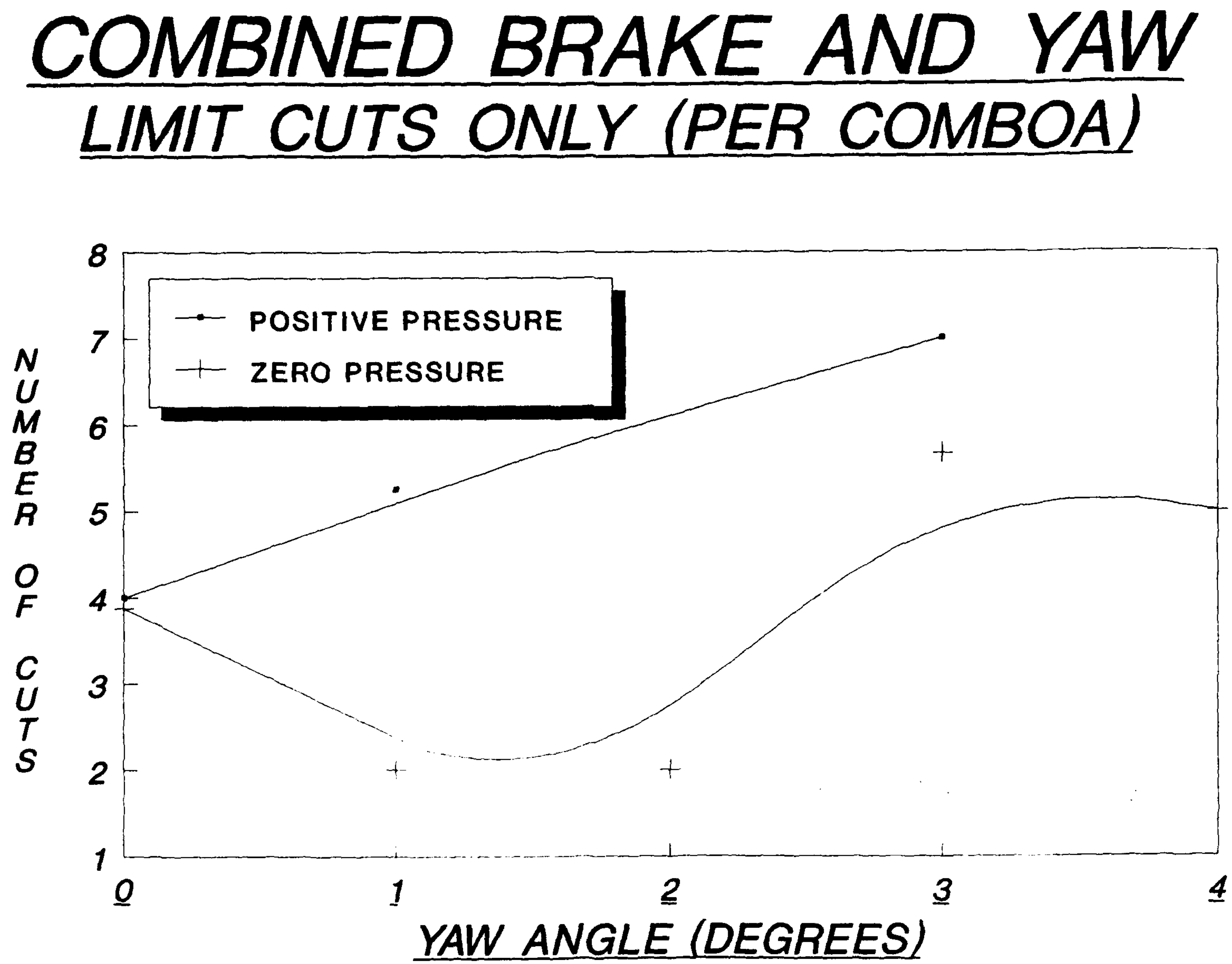


FIG-22 COMB BRAKE YAW DATA--LIMIT CUTS

TABLE 23 DISTRIBUTION EFFECTS

QUERY CONSTANTS----------> F-16 GY 275 DRY 0 CRL 0 0 0 14300 0 0 SPEED<20

TABLE 23 DISTRIBUTION EFFECTS FILE DISTRIB

TABLE DISTRIBUTION EFFECTS ANAL LIST CRITICAL ITEMS PREPARED BY: AFWAL/FIEMB/K SCHWARTZ DATE 31-Oct Oct-91

F-16/GY MAX LOAD

TEST #	DATE	ENG	AMB TEMP	A/C	MAN	AXLE	TIRE PRES	PRNT L	PRNT W	SURF COND	DEBRIS SIZE	DEBRIS TYPE	BED LTH	BED WTH	DEB PAT	BRAKE PSI	YAW	CAM	VERT LOAD	PRO VEH	PUSH DIST	BED SPEED	TOTA CUTS	0 5	6 10	11 15	16+	TOT HITS	ADJ HIT	ADJ HITS FO CUT
B	C	E	G	I	K	N	O	P	Q	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AI	AJ	AK	AL	AM	AR	AS	AU
E1-2	07 OCT 86	KS/JS	60	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	70	50	15	5	0	346	346	4.94
E1-4	07 OCT 86	KS/JS	62	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	58	35	20	2	1	346	346	5.97
E1-1	04 OCT 86	KS/JS	76	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	51	14	26	11	0	346	346	6.78
BT-19	04 OCT 86	KS/JS	7	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.0	33	19	10	4	0	346	346	10.48
J-3	23 DEC 86	KS/JS	42	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	15.0	32	16	14	2	0	346	346	10.81
D-3	03 AUG 87	JS	81	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	18.0	32	18	11	3	0	346	346	10.81
X-6	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.3	17	5	6	4	2	208	208	12.24
D2/12	31 JUL 87	JS	82	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	17.0	24	7	14	2	1	346	346	14.42
X-7	18 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	16.5	13	3	5	2	3	208	208	16.00
D1/11	31 JUL 87	JS	78	F-16	GY	F-16R	275	10.2	5.8	DRY	1.50	CRL	500	7.75	6/5	0	0	0	14300	PAYM	2300	16.5	17	6	11	0	0	346	346	20.35
X-8	18 JUL 86	KS/JS	86	F-16	GY	F-16R	275	10.2	5.8	DRY	1.25	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.1	10	6	1	3	0	208	208	20.80
X-5	16 JUL 86	KS/JS	85	F-16	GY	F-16R	275	10.2	5.8	DRY	1.00	CRL	300	6.5	5/4	0	0	0	14300	LPAY	2300	17.3	7	3	4	0	0	208	208	29.71

SECTION VI

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS:

Test Methods and Data Generation:

Overall the data from this effort proved to be of high quality. The method of testing devised was the closest possible to actual flight test data and represents a first to determine the effects of tire cutting in a hostile situation. Several critical testing barriers were successfully overcome and the method of testing employed can now be confidently used for future test needs of this type.

Data Analysis Conclusions:

As a result of this preliminary analysis, the following conclusions observations or trends were noted for the various parameters tested and analyzed:

Speed (All Cuts):
Tire cutting damage increases moderately at higher speeds.

Speed (Deep Cuts):
Tire cutting damage increases substantially at higher speeds.

Yaw (All Cuts):
A trend toward higher cutting damage at higher yaw angles exists.

Yaw (Deep Cuts):
Only minor increases in damage were noted for this case.

Radial (All Cuts):
No significant differences were noted in the total number of cuts occurring in the radial as opposed to the bias ply case.

Radial (Deep Cuts):
The radial tire data showed a significant reduction in the number of deep cuts occurring. This is offset, however, by the lower cut limit associated with the particular design tested.

Pressure Effects:
A trend exists for increasing tire cutting at higher tire pressure values.

Retread Effects:
A minor trend toward less damage for a retreaded tire may exist.

Tire Size: Due to pressure differences tested an assessment of this parameter is difficult. However, in extrapolating pressure data, smaller size tires may have a very significantly higher resistances to tire cutting.

Loads Effects:
Based on the data studied the effects of load seems insignificant relative to tire cutting damage.

Water Effects:
The effects of running over flooded surfaces appears to be very significant and damage increases of over 100% can be expected.

Yaw/Water Effects:
Limited testing in this area lead to a preliminary conclusion that the introduction of yaw on a wet surface could serve to reduce the amount of cutting damage occurring.

Debris Size:
Of all the areas investigated, size disclosed one of the most significant findings of the program. Specifically cut size and overall damage increases dramatically with increasing debris size. It also was disclosed that for the 275 psi tire tested that transversing debris sizes over 1.5 inches results in a very high probability of tire failure.

Debris Type:
The type of debris encountered (stone vs. steel) also proved to be a significant parameter. For the steel case, cutting damage can increase significantly.

Braking Effects:
With regard to braking effects no quantitive conclusions can be derived. In general, however, it appears that no significant effects occur until high brake torques are applied. In terms of drag load, a value of 1100 lbs was calculated whereby increased cutting damage comes into play.

Brake/Yaw Effects:
The effects of combining braking with yaw were not as expected. Increasing yaw angles and braking tend to increase the resulting damage. However, the combination of the two parameters does not appear to introduce significantly higher damage levels.

RECOMMENDATIONS:

Detailed Operational Models

The results of the tire cutting test effort along with this preliminary analysis and subsequent statistical studies have shown that realistic tire damage models can be developed through the addition of aircraft operational data. It is therefore recommended that airfield cleanliness models be combined with detailed aircraft operational models to obtain the improved tire reliability required in either peacetime situations or wartime postattack situations.

Additional Testing of Different Tire Sizes

This particular test effort was confined to one aircraft involving only two tire sizes and one operational spectrum. To better understand the full impact of tire cutting, more sizes involving more variations in load, speed, turning, and braking conditions are required. With the current strong baseline in hand, lower cost testing methods could be developed for such testing, and it is recommended that these approaches be pursued.

High Pressure Effects Expansion

Pressure effects is one area where the data were limited, but a trend was exhibited toward increased cutting at increased pressure. Additionally this trend could become highly significant at pressures beyond those tested. With current design trends going toward higher pressures, the influence of cutting on operations and safety could become quite significant even in a peacetime scenario. It is therefore recommended that additional tests be conducted on an F-16 main tire at pressures up to 350 psi.

LIST OF REFERENCES

1. Landing Gear & Tire Cutting Test Vehicle (Design & Capabilities Report), Ken Schwartz, WRDC/FIVMB Wright-Patterson AFB OH, TM- - , April 1990.

2. Tire Cutting Test Program (Test Report), Ken Schwartz, WRDC/FIVMB, Wright-Patterson AFB OH, TM- - , April 1990.

3. Air Base Survivability - Tire Cutting Test Plan & Program Development, WRDC/FIVMB Wright-Patterson AFB OH, TM- - , April 1990.

4. Tire Cutting Assessment Report, Ken Schwartz, WRDC/FIVMB Wright-Patterson AFB OH, Internal Memo Report for AFESC/RDCR, August 1984.

5. Cut Tire Inspection Procedure, Peter C. Vorum, WRDC/FIVMB Wright-Patterson AFB OH, WRDC-TM-90-319-FIVM, April 1990.

6. UDRI Piekutowski Report.

7. Foreign Object Damage Field Test (Revised Draft Test Report), the BDM Corporation, BDM/W-84-0291-TR.

8. Post-Attack Debris Clearance Program Tire Cutting Test Analysis, Draft Technical Report, June 6 1988, The BDM Corporation, BDM/MCL-88-0200-TR.

9. Cleanliness Requirements for Aircraft Operating Surfaces, Draft Technical Report, The BDM Corporation, BDM/MCL-87-0112-TR.

10. FOD Generation by Aircraft Tires, S J Bliss, L Cross, A J. Piekutowski, H F Swift, University of Dayton Research Institute, for AFESC/RDCR Tyndall AFB Florida, ESL-TR-82-47.

11. Design Analysis Report Tire Lofting Test Boom, Contract N68335-82-C-1389, Sverdrup Technology Inc., Tullahoma, Tennessee, Oct 1982, Tire Cutting Modification, May 1985.

12. Cut Progression During Dynamometer Testing of Foreign Object Damaged Type VII Extra High Pressure Aircraft Tires, Peter C. Vorum, WL/FIVMB Wright-Patterson AFB OH, to be released Jan 1991.

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